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IOWA

GEOLOGICAL SURVEY

VOLUME XVII

ANNUAL REPORT, 1906

WITH

ACCOMPANYING PAPERS

SAMUEL CALVIN, PH. D., STATE GEOLOGIST
JAMES H. LEES, ASSISTANT STATE GEOLOGIST

STANFORD

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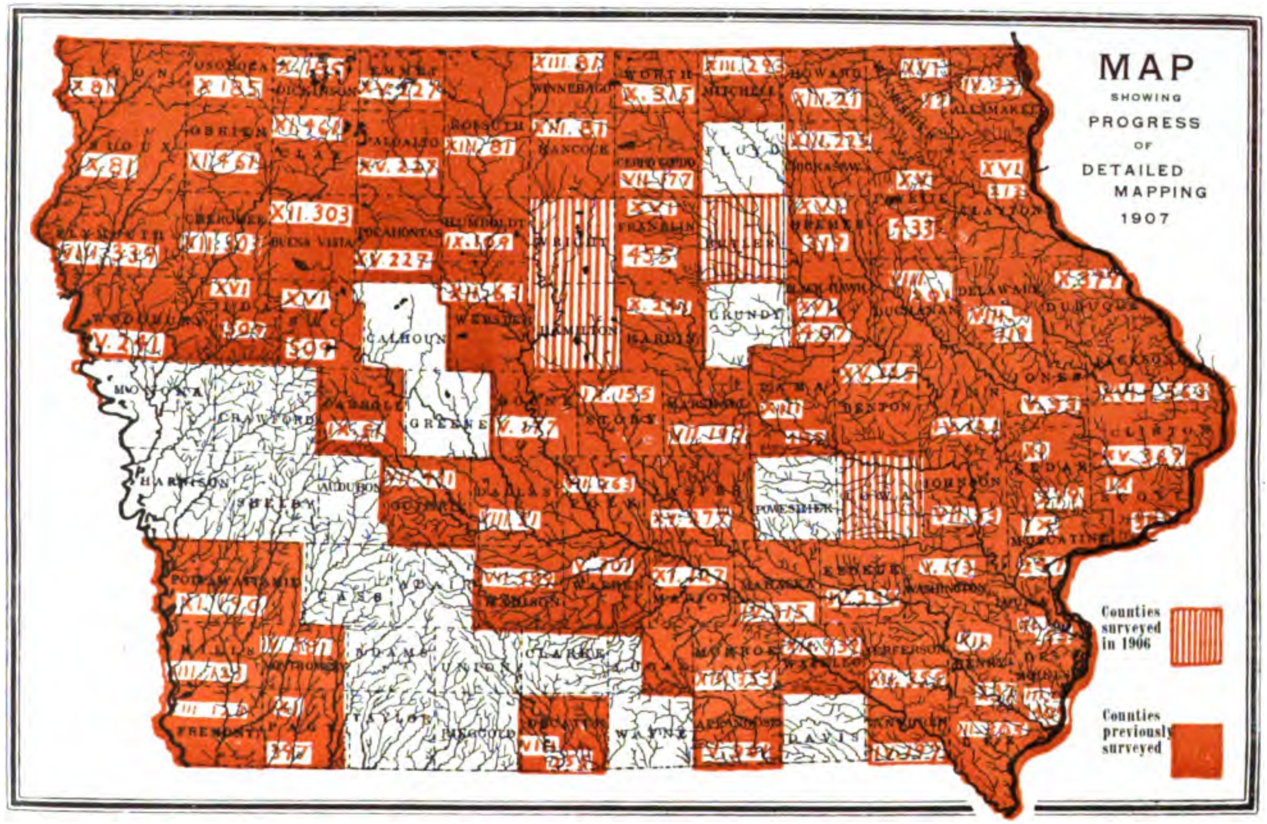
ADMINISTRATIVE REPORT


MAP
SHOWING
PROGRESS
OF
DETAILED
MAPPING
1907
Counties surveyed in 1906
Counties previously surveyed
LYON
OSCEOLA
DICKINSON
EMMET
WINNEBAGO
WORTH
MITCHELL
HOWARD
ALLAMAKEE
O'BRIEN
CLAY
PALO ALTO
KOSSUTH
HANCOCK
CERRO GORDO
FLOYD
CHICKASAW
SIOUX
PLYMOUTH
CHEROKEE
BUENA VISTA
POCAHONTAS
HUMBOLDT
WRIGHT
FRANKLIN
BUTLER
BREMER
FAYETTE
CLAYTON
WOODBURY
CALHOUN
WEBSTER
HAMILTON
HARDIN
GRUNDY
BLACK HAWK
BUCHANAN
DELAWARE
DUBUQUE
MONONA
CRAWFORD
CARROLL
GREENE
BOONE
STORY
MARSHALL
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LINN
JONES
JACKSON
CLINTON
CEDAR
HARRISON
SHELBY
AUDUBON
GUTHRIE
DALLAS
POLK
JASPER
POWESHIEK
IOWA
JOHNSON
SCOTT
MUSCATINE
POTTAWATTAMIE
CASS
ADAIR
MADISON
WARREN
MARION
MAHASKA
KEOKUK
WASHINGTON
LOUISA
MILLS
MONTGOMERY
ADAMS
UNION
CLARKE
LUCAS
MONROE
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FIFTEENTH ANNUAL

Report of the State Geologist

IOWA GEOLOGICAL SURVEY,
DES MOINES, IOWA, DECEMBER 31, 1906.

To Governor Albert B. Cummins and Members of the Geological Board:

GENTLEMEN:—Greatly to the regret of all concerned, Professor F. A. Wilder found it necessary to resign the Directorship of the Iowa Geological Survey during the year 1906, his resignation taking effect on the first of May last. The plans he had formulated for the season's work were, however, carried out as far as possible. For more than two years Professor Wilder had been engaged in a study of the coals of Iowa. Through his efforts the Iowa coals were among the first to receive attention at the Coal-Testing Plant of the United States Geological Survey at Saint Louis, and it was his plan to prosecute the work of investigation continuously till it should be completed. This personal work was, of necessity, suspended by his removal from the state. It is expected, however, that Professor Wilder will soon return to finish the investigation and prepare the report on Iowa coals in accordance with the original plans. Furthermore, about the beginning of the working season, and when it was too late to find suitable substitutes, some of the men who had been employed to take up certain other lines of work, found it impossible to carry out their engagements. Accordingly the field corps of the Survey during the last working season was smaller than usual. This condition was still further aggravated by the fact that unusual delays and difficulties, wholly unnecessary as far as appeared on the surface, were met in the printing of the annual report. The result was that the Assistant State Geologist was detained in the office during the entire working season, supervising work that should have been finished early in August at the latest. With all that could be done, the field season, in the case of this member of the geological staff, was lost. The most important line of investigation carried on by the Survey during 1906 related to the quarry products of the state. This work was done under the efficient direction of Dr. S. W. Beyer, who had as assistants in the field and laboratory Mr. Ira A. Williams and Mr. Walter B. Cole. Especial attention was given to the location, characters and extent of materials suitable for the manufacture of Portland cement. At present the people of Iowa, in common with the people of the civilized world, are interested in the question of cement materials as in scarcely any other question of purely geologic import. There is a practically unlimited market for Portland cement, its uses and applications are increasing in number and importance almost daily, and Iowa possesses the materials for its manufacture in almost limitless quantities. Letters by the score, making inquiry concerning the suitability of materials for cement making, have been received at this office during the year, and the geographical distribution of the post offices from which the letters were mailed clearly indicate an interest reaching to every corner of the state. At the present time the Mason City region is attracting more attention than any other. One company, financially strong, has located here, and others are studying the situation. The coming year will witness at least one plant in this locality in full operation. A strong company has options on lands containing coal as well as the raw materials for cement, at Harvey in Marion county, and preliminary work is progressing in a number of other localities. Iowa has been slow in recognizing her advantages in this direction, but there is now fair promise that our state will soon occupy a leading place in the production of one of the most necessary and important of modern structural materials. Professor Beyer's report on the quarries and quarry products of Iowa is herewith submitted for publication as volume XVII of the Reports of the Iowa Geological Survey.

The coal industry has flourished during the year, and the output for 1906 will show a substantial increase over that of former years. The commercial value of peat fuel has not yet been generally recognized, but the number of inquiries coming to the office would indicate an awakening of interest, and it should not be long until the resources of the state in this direction will be exploited and made to contribute to the wealth and comfort of the people. Experiments carried on in the Province of Ontario, Canada, render it practically certain that, with properly constructed machinery, peat may be made to compete with coal in economy and efficiency as a fuel for ordinary purposes of heating, while the Saint Louis experiments with the producer gas engine indicate the high value of this fuel as a source of power. The alarming and distressing effects of the fuel famine which now prevails in some of our neighboring states, emphasize the desirability of conserving and utilizing to the utmost each and all of our fuel resources.

The United States Geological Survey has continued its work in topographic mapping in Iowa, during the past season. The extent of the work so accomplished can be best set forth by quoting from the Annual Report of the Director of the National Survey for the fiscal year 1905-6. Speaking of Iowa he says "Two parties were engaged in field work during the season. The survey of the Des Moines quadrangle, in Polk and Warren counties, and of the Nebraska City (Nebraska-Iowa-Missouri) quadrangle, in Fremont county, was completed. This work is for publication on the scale of 1 : 62,500, with a contour interval of 20 feet. There were mapped in the course of this work 256 square miles in the above named quadrangles, and in addition 35 square miles beyond quadrangle limits; 587 miles of spirit levels were run, in the course of which 19 permanent bench marks and 4,466 elevations were determined; and 772 miles of linear road traverse were run."

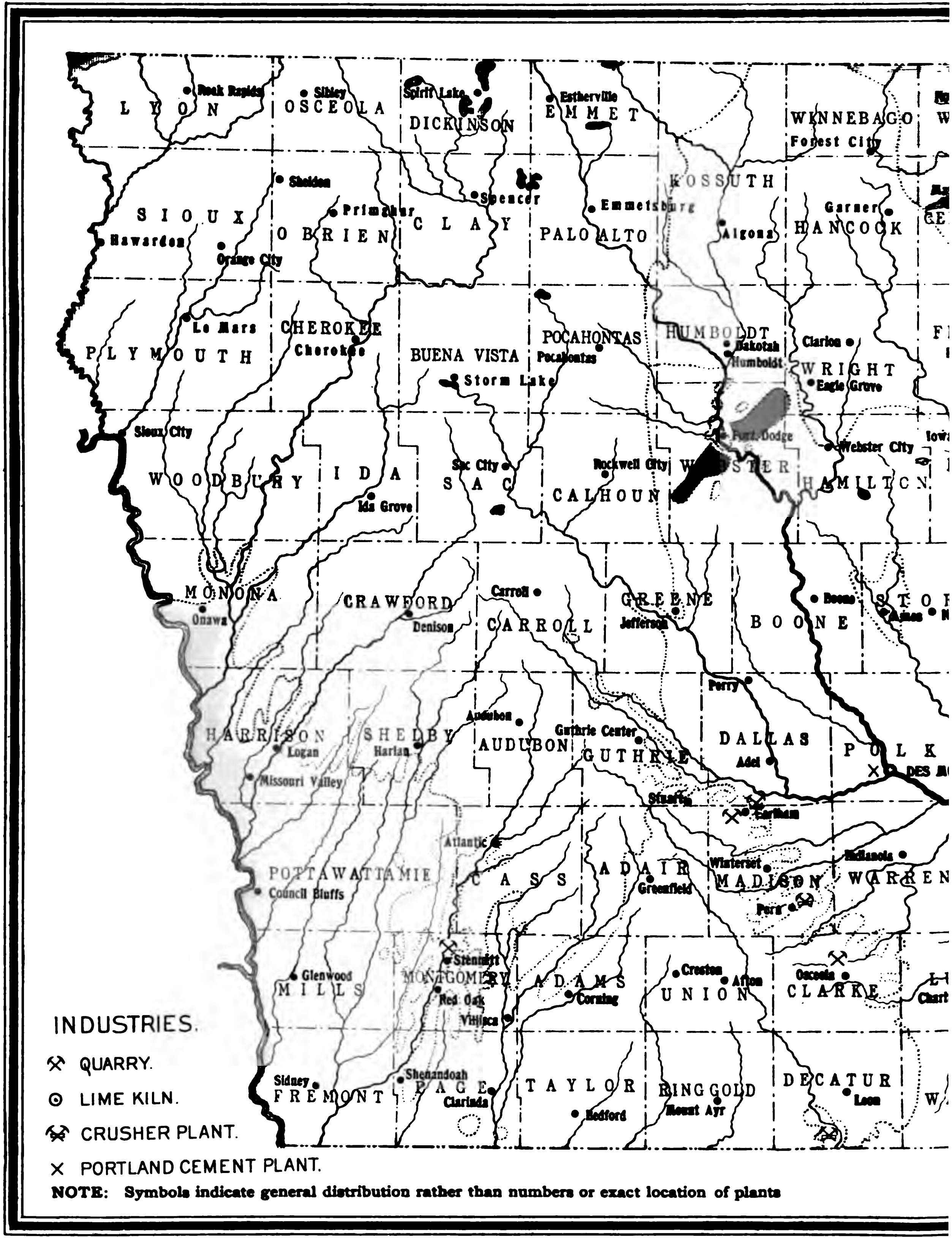
In northeastern Iowa the topography has been developed by erosion of the indurated rocks, and the geologic mapping of the region becomes impossible without a topographic base map. This the United States Geological Survey has furnished by work done in the state during the past ten or twelve years, and the geological maps of Dubuque, Clayton, Fayette, Winneshiek and most of Jackson are based on the topographic work of the National Survey. At the request of the Iowa Survey the topographic survey in Iowa has recently been transferred to the region of productive coal measures near Des Moines. Many of the problems relating to the occurrence of coal can be best studied in connection with an accurate topographic map, and it is the hope that the great productive coal area from Fort Dodge southward to the Missouri line will soon be covered with the topographic sheets of the United States Survey. By the action of the Legislature the State Survey may co-operate with the national bureau in hastening the work of topographic mapping. The State Survey will pay not more than half of the field expenses, while the National organization will pay the remainder and will assume all the expense of engraving and printing the topographic sheets.

Apart from the work incident to the study of the cement materials and other quarry products, field work has been prosecuted in a number of counties. Prof. M. F. Arey has completed a survey of Butler county, Prof. S. W. Stookey has worked in Iowa county, and Prof. T. H. Macbride has completed the field work in Wright and Hamilton counties. In addition to the work in the two counties named Professor Macbride has made a careful study of the distribution of flowing wells which have their origin in the Pleistocene deposits, extending his observations from the Minnesota line as far south as Poweshiek and Iowa counties. The information so collected is of very great interest and value.

The study of the underground waters of Iowa has been continued under the direction of Professor Wm. H. Norton, the expenses of the field work having been met by the U. S. Geological Survey. A very full report will soon be ready for publication.

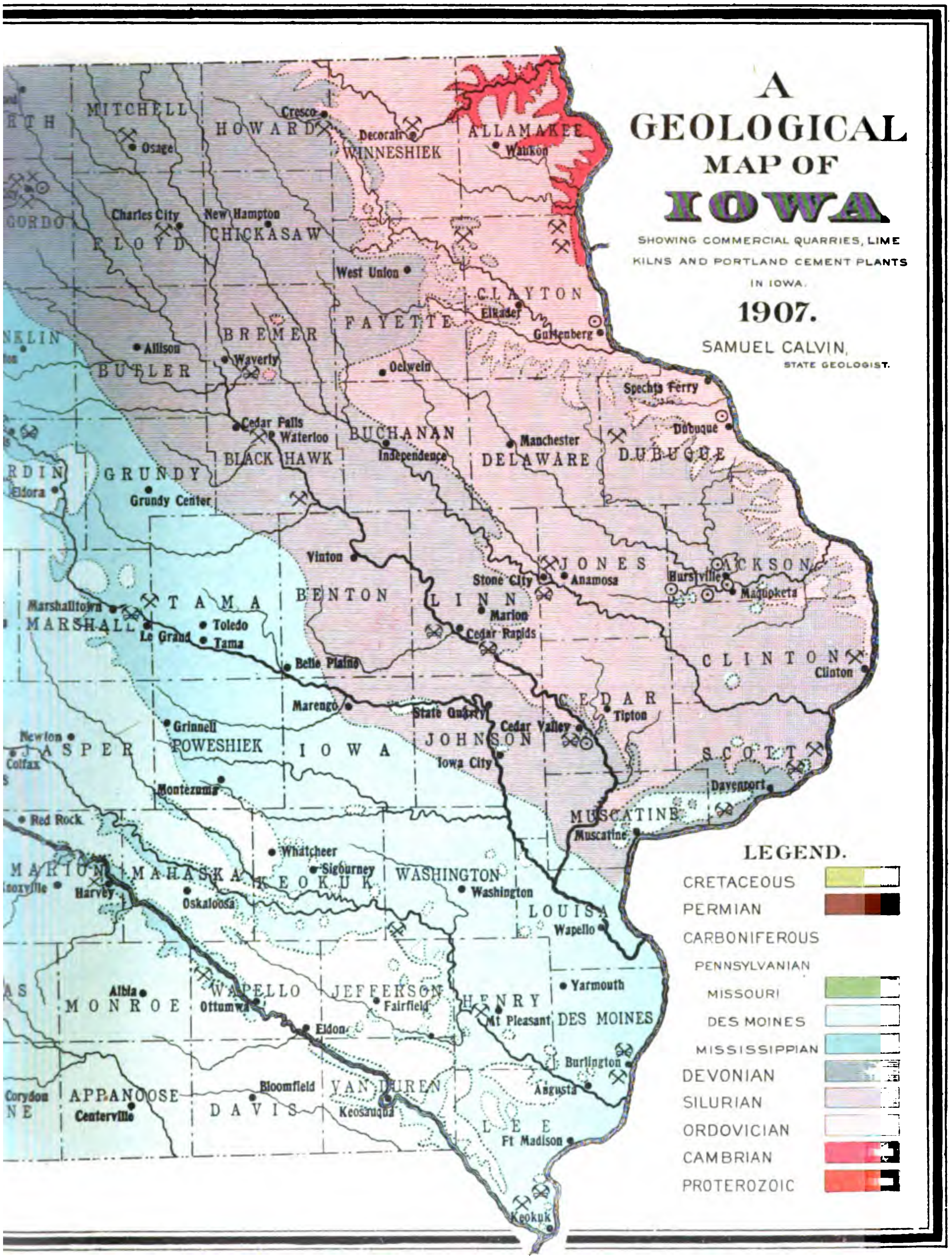
With your sanction the Iowa Survey has co-operated with the Geological Survey of Illinois in the study of certain physiographic and geologic problems, of especial value from a scientific and educational point of view, found on both sides of the Mississippi river between Dubuque and Davenport.

Professor B. Shimek has continued his studies of the loess, gathering material for an exhaustive monograph on this important and exceedingly interesting formation. The loess constitutes the soil over a very large area of Iowa, and loess soil



NOTE: Symbols indicate general distribution rather than numbers or exact location of plants

IOWA LITHO CO.



A GEOLOGICAL MAP OF IOWA

SHOWING COMMERCIAL QUARRIES, LIME KILNS AND PORTLAND CEMENT PLANTS IN IOWA.

1907.

SAMUEL CALVIN,
STATE GEOLOGIST.

LEGEND.

CRETACEOUS
PERMIAN
CARBONIFEROUS
PENNSYLVANIAN
MISSOURI
DES MOINES
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
PROTEROZOIC

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on surfaces of moderate slope is one of the most valuable, the most productive, the most easily cultivated. The supremacy of Iowa in the production of corn and all related products of the farm, is due in no small degree to the peculiarities of the loess and to the very extensive area over which it is spread. All studies, therefore, that can throw light on its history and origin are to be encouraged, and it is a pleasure to recognize the fact that in Professor Shimek we have the man best qualified by long observation and experience to undertake a thorough investigation of this remarkable and much misunderstood deposit. The results of his work will soon be ready for your consideration.

Dr. Charles R. Eastman of Harvard University has, for some time, been at work on a study of the Devonian fishes of Iowa. In no other state has such a large and interesting assemblage of fossil fish remains of Devonian age been found, and it is with pleasure and no small degree of pride that we look forward to the time, in the near future, when the unique types and full scientific significance of our Devonian fish fauna will be given to the world through the medium of the publications of the Iowa Geological Survey.

Our whole Devonian system deserves the most careful study. On the one hand are its extensive deposits of clays, cement rocks and other economic materials demanding attention on account of their commercial importance, and on the other hand are its many remarkable groups of ancient forms of life inviting study from a more purely scientific point of view. The Iowa Devonian differs in marked ways from Devonian sections in other parts of our country. It is already a standard in the world of geologic science, but it still needs thorough, detailed investigation and description to bring out all the characteristics of economic and scientific importance, which for the benefit of the future citizen and student, should be placed on permanent record. To Iowa the scientific world has learned to look for the standard American section of the deposits of the great ice age, for here the records of the successive glacial invasions of the Pleistocene period are most complete and have been most satisfactorily deciphered. The unusually favorable opportunities afforded by the geological formations of the state to shed light on a number of important world problems, impose obligations that ought not to be neglected. Iowa owes it to herself and to science to make known to the world her wealth of scientific facts, as well as her economic products.

The increasing use made of the reports of the Survey in High Schools and Colleges, in connection with studies relating to the Geography, Physiography, Geological structure and Economic resources of the state, is very encouraging; for the general call for literature descriptive of Iowa, in a form that may be used in classes, indicates the growth of clearer knowledge on the part of the citizens to be, concerning the state and its possible geologic products. Many thousands of dollars have, in the past, been spent in uninformed efforts to discover deposits of commercial importance at points where such deposits could not possibly exist. To help our people to see what our resources are and how to proceed intelligently to develop them, is to render them a service of the highest value. Among the educators of the state there is a great demand at present, a demand that is sure to grow as the years go by, for a moderate sized volume descriptive of the state as a whole, and I recommend that, as soon as possible, an effort be made by the Survey to meet this demand.

Progress has been made during the year in collecting and arranging the material for the general volume on the Geology of Iowa. It will be some time before the work can be completed. This volume will necessarily be larger, fuller and more technical than the educational volume contemplated in the preceding paragraph.

I have the honor to remain, gentlemen,

Yours very sincerely,

SAMUEL CALVIN.

REPORT OF THE ASSISTANT STATE GEOLOGIST

IOWA GEOLOGICAL SURVEY,
DES MOINES, DECEMBER 31, 1906.

DEAR SIR:—I have the honor to submit the following report of my work during the year 1906:

I was called to take charge of the Des Moines office of the Survey on the first of May upon the resignation of Mr. Savage and at once began assisting him in the compiling of the large geological map of the state which accompanies volume XVI of the reports. After this the work of proof-reading the Supplementary Report on Portland Cement Materials in Iowa, by Professor S. W. Beyer, occupied some time. This report constitutes Bulletin No. 3 of the Survey reports.

After the completion of this work the preparation of the different papers of volume XVI for the printer was undertaken, also the supervision of the making of the plates for illustrating the volume. A task which involved a great amount of time and detailed work was that of revising and correcting the proofs of the county and state maps which were made this year, including those for Winneshiek, Jackson, Bremer and Franklin counties. Especial care has been taken to have these maps uniform in color schemes and patterns with the best maps of previous volumes. In the case of the wall map of the state the colors used are the same as those adopted for the recent geological map of North America issued conjointly by the Canadian, United States and Mexican Surveys.

Owing to great delay in setting up the material of the report, the printing was not completed until late in the autumn and hence there was no opportunity for carrying on any field work, but the entire summer had to be spent in the office. It is now clear that at least two months spent in expectation of proof from the printer might have been used to good advantage in the field and the report published as early as was ultimately the case. As it was, the report was not delivered to this office until the close of the year. It is much to be hoped that future volumes can be issued without so much unnecessary delay.

The last few days of the year have been spent at Iowa City in making a complete set of photographs from the negatives in the possession of the Survey and of the Director. This set when bound will be a valuable addition to the library of the Survey. A similar but somewhat less complete set will be mounted in a case in the Survey museum for more ready inspection by visitors.

A large amount of correspondence has been carried on with persons who are interested in the natural resources of the state. Many persons and corporations are desirous of learning the advisability of investing capital in the Portland cement industry and we have been called upon to furnish such information as we possess. This we have done and have in this way distributed a large number of copies of Bulletin No. 3, and of the paper by Bain and Eckel on Cement and Cement Materials of Iowa, which appeared in volume XV of the annual reports. Interest in the clay and other industries of the state is also active both within and without our state and we are frequently in receipt of requests for reports and other data.

In addition there have been sent to the office numerous samples concerning the economic value of which, information has been desired. So far as possible this information has been furnished and considerable time and labor have been given to this part of the work and to making such qualitative determinations as are possible with the equipment at hand.

During the current year there has been collected and turned into the State Treasury from the sale of reports, as required by law, $62.79.

The following publications have been added to the library of the Survey:

United States Geological Survey: 26th Annual Report, 1904-1905.
    Monograph 48; Status of Mesozoic Floras of U. S., Ward.
    Mineral Resources of the United States, 1904.
    Bulletins 268-301.
    Water Supply Papers 153-186.
    Professional Papers 43-55.

Annual Report of the Smithsonian Institution, 1904.
Proceedings of the U. S. National Museum, Vols. 29 and 30.
Geological Survey of Ohio, Bulletins 4, 5 and 6.
Topographic Survey of Ohio, 1904.
Geological Survey of New Jersey, Annual Report, 1905.
North Carolina Geological Survey, Building and Ornamental Stones.
Department of Geology and Natural Resources of Indiana, 30th Annual Report, 1905.
North Dakota Agricultural College Survey: Biennial Report, 1903-4.
Maryland Geological Survey; Report on Pleistocene and Pliocene.
Kentucky Geological Survey; Report of Progress, 1905, Bulletins 1, 2, 4, 5.
Illinois Geological Survey, Bulletins 1-3.
Missouri Botanical Garden, 1906.
Bulletins of Ohio Department of Agriculture.
Bulletins of Georgia State Board of Entomology.
Ohio State University, Mycological Bulletins.
Bulletins of the University of Montana.
Colorado College Publications.
Bulletins of the Department of Geology of the University of California, Vol. 4.
Science Bulletin of the University of Kansas, Vol. III.
Proceedings of the Davenport Academy of Sciences, Vol. XI.
Missouri Historical Society Collections, Vol. 2.
Transactions of the Academy of Sciences of St. Louis, Vol. XVI.
Proceedings of the Rochester Academy of Sciences, Vol. 4.
Journal of the Cincinnati Society of Natural History, Vol. XX.
Transactions of the American Institute of Mining Engineers, Vol. XXXVI.
Technology Quarterly, Vol. XIX.
Coal Trade Journal, Vol. XLV.
Black Diamond, Vols. 36 and 37.
Engineering and Mining Journal, Vols. 81 and 82.
Cement and Engineering News, Vol. XVII.
Rock Products, Vol. V.
Clay Record, Vols. 28 and 29.
Clay Worker, Vols. XLV and XLVI.
Brick, Vols. XXIV and XXV.
American Producer, Vol. V.
Mines and Minerals, Vols. XXVI and XXVII.
Geological Survey of Canada, Vols. XIV and XV.
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Proceedings of the Geologists' Association, London, Vol. XIX.
Transactions of the North of England Institute of Mining and Mechanical Engineers, 1906.
Memoirs and Proceedings of the Manchester Literary and Philosophical Society, Vol. 50.
Transactions of the Royal Geological Society of Cornwall, England, Vol. XIII.
Proceedings of the Royal Society of Edinburgh, Vols. 25 and 26.
Proceedings of the Royal Philosophical Society of Glasgow, Vol. XXXVI.
Geological Commission of the Cape of Good Hope; 10th Annual Report, 1905.
Geological Society of South Africa, 1906.

Geological Survey of Queensland, Report, 1905, 1906.
South Australia, Mining Operations in, 1905, 1906.
South Australia Geological Survey, 1906.
Western Australia Geological Survey, 1906.
Victoria Department of Mines, Annual Reports, 1905, 1906.
New South Wales, Geological Survey, Vol. VIII, 1905.
New South Wales, Department of Mines, Annual Report. 1905.
Memoirs, 1905.
Proceedings of the Royal Society of Victoria, Vol. XVIII, 1906.
Transactions of the Australian Institute of Mining Engineers, Vol. XI, 1906.
New Zealand Geological Survey, Bull. No. 1, 1906.
Boletins del Instituto Geologico de Mexico, 1905, 1906.
Publications of Sociedad Cientifica "Antonio Alzate," Mexico, 1905.
Anales de la Academia de Ciencias de la Habana, Vol. XLII, 1906.
Bulletins Commisao Geog. and Geol. do Sao Paulo, Brazil.
Revista da Sociedade Scientifica de Sao Paulo, 1905.
Boletin del Cuerpo de Ingenieros de Minas del Peru, 1906.
Anales del Museo Nacional de Buenos Aires, 1905.
Mitteilungen des Vereins für Erdkunde zu Leipzig, 1903, 1904.
Geognostische Jahreshefte, 1904.
Jahrbuch der St. Gallisches naturwissenschaftlichen Gesellschaft, 1905.
Verhandlungen der schweizerischen naturforscheiden Gesellschaft in Luzern, 1905.
Vierteljahrschrift der naturforscheiden Gesellschaft in Zurich, 1906.
Sammlungen des Geologischen Reichsmuseums in Leiden, Vol. VIII, 1906.
Tromso Museum Publications, 1904.
Sveriges Geologiska Undersökning, 1906.
Nyt Magazin for Naturvidenskaberne, Christiania, Vol. 44, 1906.
Bulletin de la Commission Geologique de Finlande, 1905.
Publications of Bergen Museum, 1905, 1906.
Verhandlungen der russisch kaiserlichen mineralogischen Gesellschaft zu St. Petersburg, 1905.
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Acta Universitatis Lundensis, 1902-1905.
Bulletin of Geol. Institution of University of Upsala, 1905.
Bulletins de la Societe Belge de Geologie, 1905, 1906.
Commission Geodesique Neerlandaise; Determinations of Latitude and Azimuth.
Bulletin Museum D'Histoire Naturelle, Paris, 1906.
Bulletin Societe Neuchateloise des Sciences Naturelles, No. XXXII, 1903, 1904.
Bulletin de la Societe Geologique de Normandie, Vol. XXV, 1905.
Bulletin de la Societe Vaudoise des Sciences Naturelles, Vols. XLI and XLII, 1905, 1906.
Le Globe, Journal Geographique, Vol. XLV.
Revista de la Real Academia de Ciencias de Madrid, Vol. IV, 1906.
Memorias of above Academia, Vols. 22 and 24, 1905, 1906.
Publications of Commissao do Servico Geologico de Portugal, Vol. VI, 1904-1905.
Societa Geographica Italiana, Vol. VII, 1906.
Atti della Societa Italiana di Scienze Naturali, Milan, Vol. XLV, 1906.
Publications of Geological Survey of Japan.

Very sincerely yours,
JAMES H. LEES.

TO PROFESSOR SAMUEL CALVIN, State Geologist.

MINERAL PRODUCTION IN IOWA

IN 1906

BY

S. W. BEYER

VALUE OF MINERAL PRODUCTION

1904

Coal	$10,439,496
Clay	3,487,376
Stone	542,170
Gypsum	469,432
Lead	2,619
Sand-lime brick	13,907
Total	$14,955,000

1905

Coal	$10,495,593
Clay	3,408,547
Stone	533,509
Gypsum	589,055
Lead	1,500
Sand-lime brick	38,642
Mineral water[*]	36,200
Total	$15,103,046

1906

Coal	$11,619,455
Clay	3,477,237
Stone including lime	577,782
Gypsum	573,498
Lead and zinc	26,300
Sand-lime brick	38,255
Mineral water[*]	27,540
Sand and gravel	74,380
Total	$16,414,447

[*] Mineral paint is combined with mineral water.

MINERAL PRODUCTION IN IOWA FOR 1906.[*]

BY S. W. BEYER.

The mineral production for 1906 totals considerably over a million dollars more than for 1905. The principal gain is in the value of the coal output which shows not only an increased tonnage but also an increase in price for the year. The production of sand and gravel is included in mineral production for the first time in a report of the Iowa Geological Survey. As in the case of quarry products it is almost impossible to secure accurate figures on account of the large number of small operators who produce only for their own use. The aggregate output is undoubtedly much greater than the figures show.

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[*] The policy of co-operation practiced during the past ten years between the Federal and State Surveys was materially modified for 1906. All, or practically all, of the correspondence was carried on from the central office at Washington. A list of the producers who could not be called up by letter was furnished the local office and these, as far as practicable, were visited by a representative of the State Survey. Tabulation sheets were supplied by the U. S. Geological Survey for Coal, Clay, Stone, Gypsum, Mineral paints, Sand-lime brick and Sand and gravel. The Statistics for lead and zinc, cement products, and iron ore were collected and compiled by the local office. It is a matter of regret that the data supplied will not permit tabulation by counties for all of the mineral products.

Coal.

The production of coal for 1906 shows a healthy growth in the industry for the year. This growth represents more than simply increased tonnage. Many of the larger companies installed during the year betterments in the surface equipment and mechanical haulage underground. The Consolidation Coal Company has in addition installed coal cutting machinery, greatly increasing the efficiency of the plants.

The subjoined table shows the growth in tonnage, value, average price per ton, average number of days worked and average number of men employed during the past eight years, according to the authority of the U. S. Geological Survey:

YEAR	TOTAL TONS	VALUE	AVERAGE PRICE	AVERAGE NUMBER OF DAYS WORKED	AVERAGE NUMBER OF MEN EMPLOYED
1899	5,177,479	$ 6,397,338	$ 1.24	229	10,971
1900	5,202,939	7,155,341	1.38	228	11,608
1901	5,617,499	7,822,805	1.39	218	12,653
1902	5,904,766	8,660,287	1.47	227	12,434
1903	6,365,233	10,439,139	1.64	232	13,583
1904	6,507,655	10,439,496	1.60	213	15,373
1905	6,798,609	10,586,381	1.56	209	15,113
1906	7,266,224	11,619,455	1.60	224	15,260

The output, disposition, value, average price per ton, average number of days worked and average number of men employed by counties is given in tabulated form below.

COAL PRODUCTION OF IOWA IN 1906, BY COUNTIES.

COUNTY	Loaded at mines for shipment	Sold to local trade and used by employees	Used at mines for steam and heat	Total quantity	Total value	Average price per ton	Average number of days active	Average number employees
	Short Tons	Short Tons	Short Tons	Short Tons				
Adams	200	11,488	36	11,724	$ 27,154	$ 2.32	150	67
Appanoose	1,039,610	47,842	14,143	1,101,595	2,112,169	1.92	199	3,254
Boone	213,677	14,767	4,666	233,110	436,497	1.87	179	844
Greene	2,400	16,306	1,110	19,816	40,377	2.04	178	62
Guthrie	2,128	9,895	40	12,063	31,307	2.60	140	68
Jasper	353,914	16,193	18,475	388,582	627,653	1.62	224	835
Keokuk	1,000	15,504	640	17,144	32,067	1.87	174	46
Mahaska	551,392	31,167	19,928	602,487	876,041	1.45	229	1,126
Marion	339,445	22,894	10,411	372,750	530,847	1.42	208	640
Monroe	2,369,445	37,458	51,570	2,458,473	3,345,264	1.36	248	3,712
Polk	1,095,573	238,410	35,523	1,369,506	2,363,393	1.73	252	2,793
Taylor	12,255	6,777	20	19,052	40,909	2.15	177	82
Van Buren	9,825	2,209	103	12,137	24,418	2.01	174	39
Wapello	166,757	72,443	4,056	243,256	378,072	1.55	198	578
Wayne	117,850	18,744	100	136,694	260,178	1.90	214	433
Webster	98,118	8,868	2,536	109,522	218,180	1.99	224	323
Other counties (*a*) and small mines	87,619	62,687	8,007	158,313	274,929	1.74	209	358
Total	6,461,208	633,652	171,364	7,266,224	$ 11,619,455	$ 1.60	224	15,260

a Dallas, Jefferson, Lucas, Page, Scott and Warren.

It is apparent when the above table is compared with the corresponding table for 1905 that of the leading coal producing counties, Appanoose, Jasper, Marion, Monroe, Polk and Wapello show good increases while Boone, Mahaska, Wayne and Webster show a decline. Keokuk and Lucas have dropped out of the list of large producers. Considerable exploratory work has been done in the latter county during the past few years with encouraging results and it may be confidently predicted that Lucas will regain its place with the large producers in the near future.

According to the authority of the U. S. Geological Survey, Iowa ranked ninth in production and eighth in value of the bituminous coal output for 1905. The ten leading producers for the year were as follows:

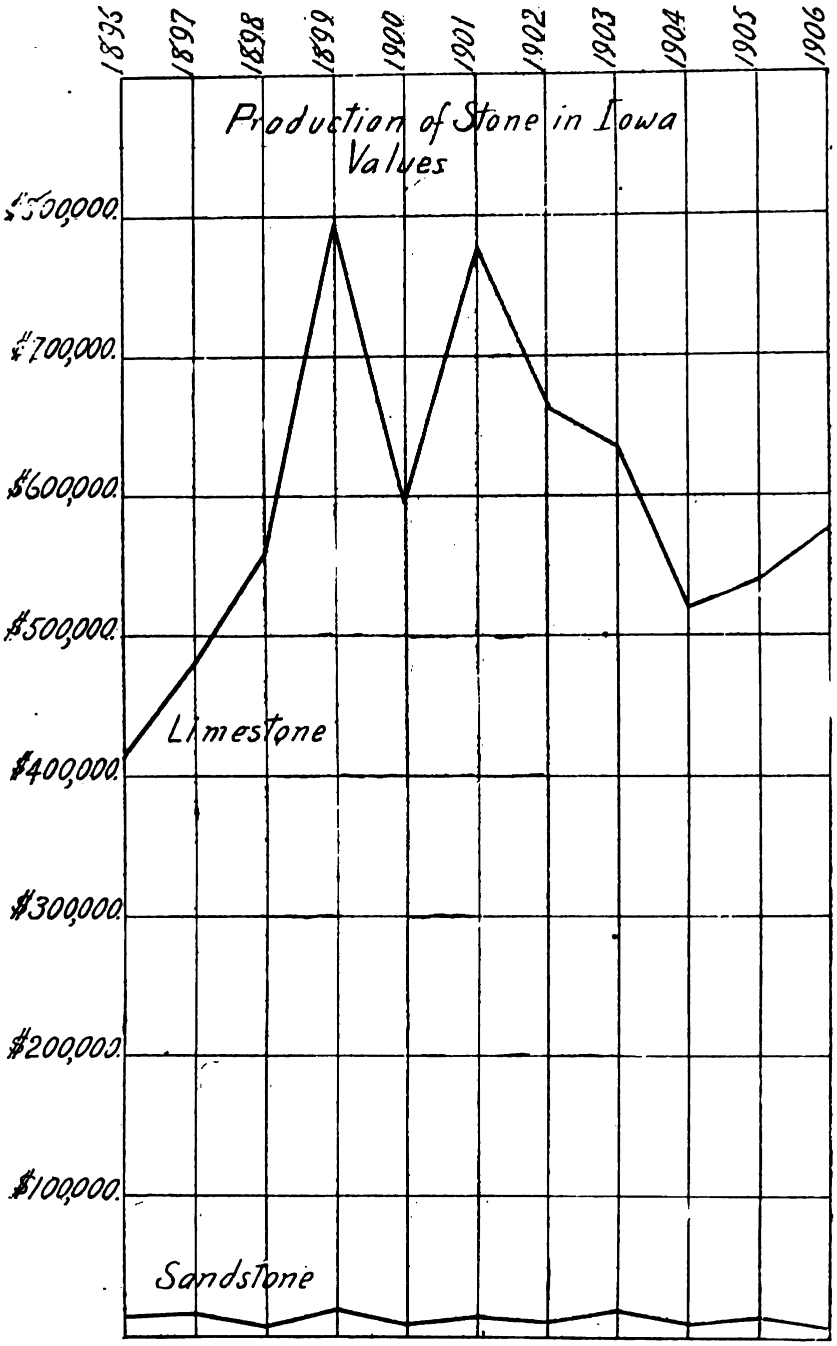
STATE	TONNAGE	VALUE
1 **Pennsylvania**	118,413,637	$ 113,390,507
2 **Illinois**	38,434,363	40,577,592
3 **West Virginia**	37,791,580	32,341,790
4 **Ohio**	25,552,950	26,486,740
5 **Indiana**	11,895,252	12,492,255
6 **Alabama**	11,866,069	14,387,721
7 **Colorado**	8,826,429	10,810,978
8 **Kentucky**	8,432,523	8,385,232
9 **Iowa**	6,798,609	10,586,381
10 **Kansas**	6,423,979	9,350,542

The outlook for 1907 is for a continuance of the high price per ton with possibly a slight decrease in output.

Clay.

Iowa Clay products sold during the year 1906 were distributed as follows:

	THOUSANDS	VALUE
Common brick	169,771	$ 1,125,009
Vitrified paving brick	16,930	185,990
Front brick	8,871	101,795
Fire brick	57	930
Drain tile		1,721,614
Sewer pipe		114,241
Hollow building tile or block		162,664
Miscellaneous		5,084
Total		$ 3,417,327



2 PLATE II.—Production of stone in Iowa from 1896 to 1906.

	VALUE
POTTERY	
Red earthern ware	$ 10,100
Stone ware	44,500
Miscellaneous	3,400
Total	$ 58,000

	TONS	VALUE
CLAY MINED		
Fire clay	355	$ 560
Miscellaneous	1,650	1,350
Total	....	$ 1,910

The state still maintains her lead in the manufacture of drain tile, Indiana and Ohio being her closest competitors.

Stone.

The value of stone produced for 1906 shows a slight increase over the preceding year. The output was distributed as follows:

Limestone:		
Rough building	$ 105,203	
Dressed building	31,350	
Paving	6,527	
Curbing	8,030	
Flagging	7,632	
Rubble	84,553	
Riprap	35,810	
Crushed stone:		
Road making	38,189	
Railroad ballast	26,268	
Concrete	142,124	
Miscellaneous	8,129	
Lime burned	78,366	
		$ 572,181
Sandstone		5,601
Total		$ 577,782

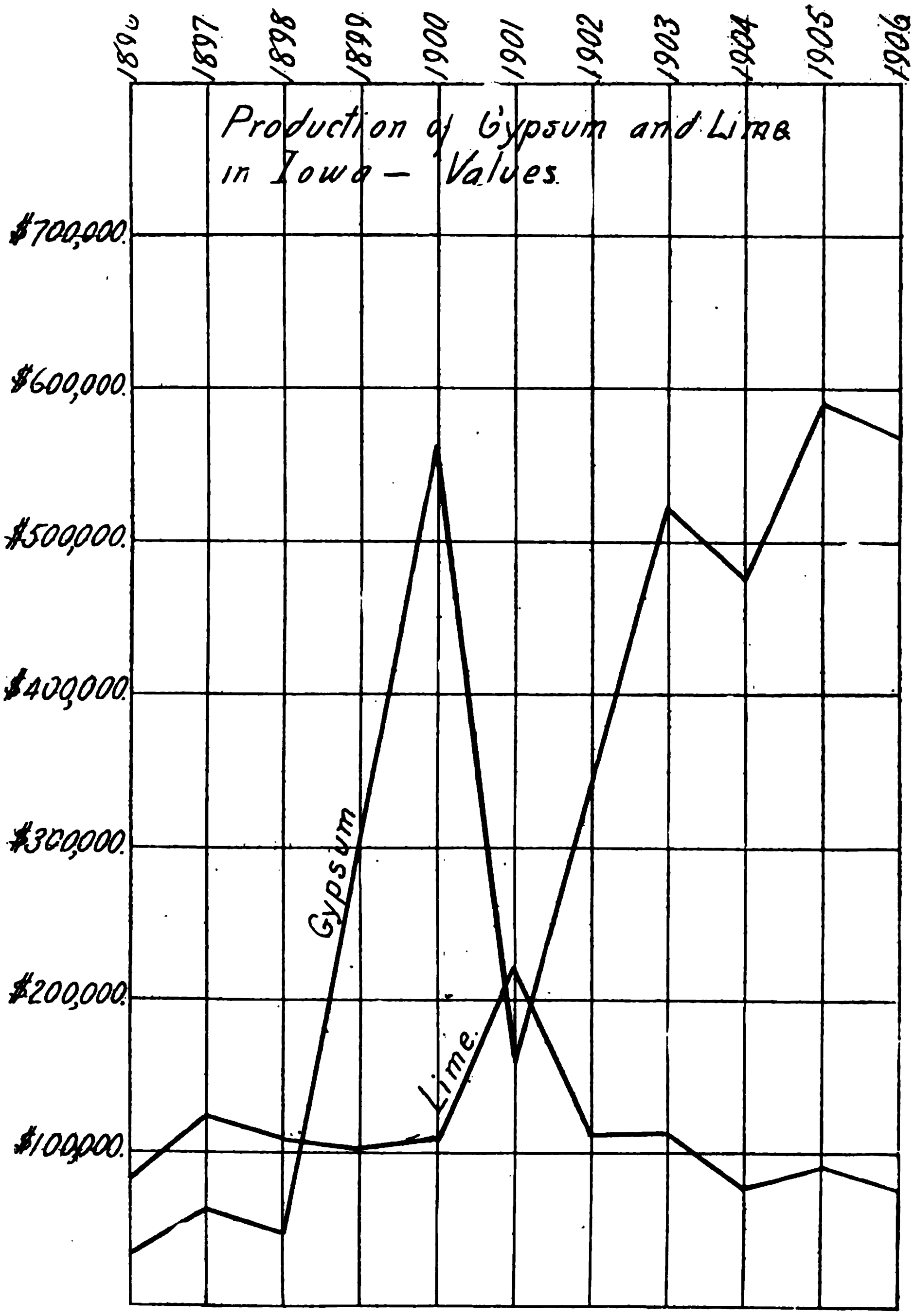


PLATE III.—Production of Gypsum and Lime in Iowa from 1896 to 1906.

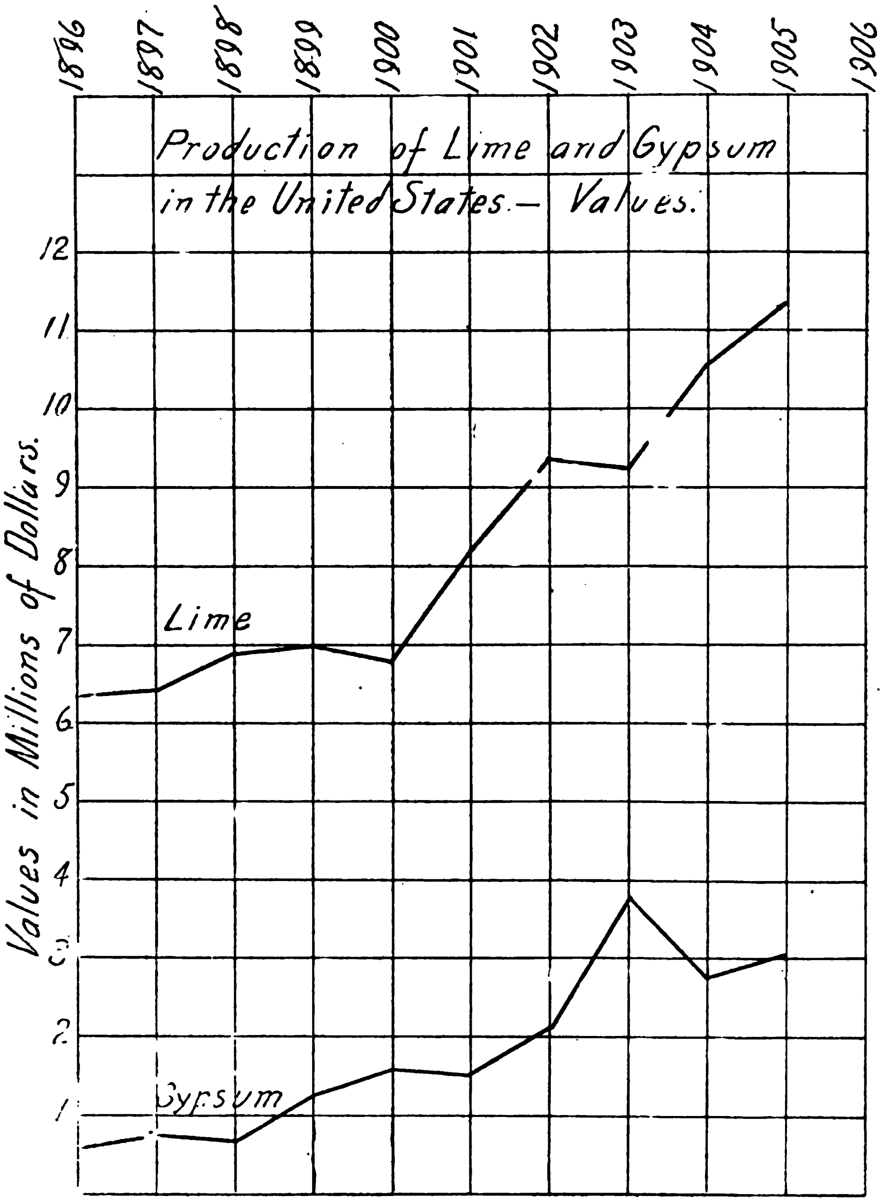


PLATE IV.—Production of Lime and Gypsum in the United States from 1896 to 1905.

Gypsum.

The total production shows a slight decline when compared with the preceding year. Two new plants were built but were not put in operation until early in 1907. The statistics of the industry for the year 1906 are as follows:

	TONS	VALUED AT
Quantity crude gypsum mined	286,857	$ 199,222
Distributed as follows:		
Sold crude—		
To Portland cement mills	8,390	11,973
As land plaster	3,751	6,922
Miscellaneous uses	1,472	3,441
Sold as Plaster-of-Paris, Wall Plaster, etc	146,526	551,162
Total	160,139	$ 573,498

Sand and Gravel.

The Survey publishes for the first time since its organization statistics of production for sand and gravel. Of necessity, reports could be secured only for the commercial pits. The pit products may be classified as follows, calculated in short tons:

	QUANTITY	VALUE
Molding sand	4,952	$ 5,152
Building sand	127,271	45,158
Fire sand	1,800	1,400
Engine sand	8,550	2,100
Other sand	14,975	4,863
Gravel	27,125	15,707
Total	184,673	$ 74,380

Lead and Zinc.

Mining and exploratory operations were carried on with more than the usual vigor during the year in the Dubuque region. This was due largely to the greater demand for both lead and zinc. The price of lead ore reached $42.50 per thousand during the year, the highest in more than a third of a century.

LEAD.

About 600,000 pounds of lead ore were produced in Iowa during the year and were sold at an average price of $33.00 per thousand pounds. The price at the end of the year was on the advance and a consequent increase in output for 1907 is expected.

ZINC.

For a number of years no zinc ore has been marketed from the Dubuque region. The year 1906 marks the rejuvenation of the industry. About 500 tons of "dry bone" were sold at an average of $13.00 per ton. While no "jack" was shipped a considerable quantity of the disseminated zinc sulphide ore was mined and is now held in stock ready to be milled. A fifty-ton mill is now in process of construction by the Avenue Top Mining Company and will be ready for operation September 1, 1907. The mill is so arranged that its capacity can be doubled easily. It is reported that the Superior Mining Company contemplates building a mill in the near future.

Several companies have discovered and are now opening up extensive ore bodies and are only awaiting better facilities for cleaning and handling the output before mining on a large scale is undertaken. The outlook for the immediate future of the district is brighter than for many years and a greatly increased output for 1907 may be predicted with confidence.

SUMMARY OF PRODUCTION FOR 1906.

Lead (Galena) 600,000 pounds	$ 19,800
Zinc (Dry Bone) 500 tons	6,500
Total	$ 26,300

Iron.

Iowa marketed no iron ore during the year 1906. The year was not, however, without results as to the future of the iron industry in the state. The Missouri Iron Company with headquarters in Saint Louis has for more than eighteen months been exploring Iron Hill near Waukon, and neighboring well known iron ore bodies with the result that they are at the present time installing a modern washer to handle six hundred tons of finished ore per day. The plant will be supplied with power by a 400-horse power gas producer engine direct connected to D. C. generators and all crushers and other machinery will be direct connected to motors. It is believed that by washing, jigging and roasting the metallic iron content of the ore can be brought up to between 55 and 60 per cent. The ore will probably be shipped by rail to the river and then by boat to Saint Louis for reduction.

Mineral Water.

The bottling and shipping of mineral water has become an established industry in Iowa. The most important producers are the springs at Colfax in Jasper county. The amount sold for 1906 was 227,500 gallons valued at $23,700 or at an average price of eleven cents per gallon. It was distributed as follows:

Medicinal water	$ 23,150
Table water	550
Total	$ 23,700

PORTLAND CEMENT.

The year 1906 was important in the history of the development of the mineral resources of the state in the fact that two Portland cement companies were organized and commenced the building of plants at Mason City and Des Moines, respectively. The former plant will reach completion on or about November 1, 1907. The Des Moines plant will not be in operation before the middle of 1908. A third company has been organized recently and is planning to erect a plant at Harvey, in Marion county.

Cement Products.

The increase in the use of Portland cement is little less than phenomenal. The manufacture of cement products has become a recognized industry in a large proportion of the towns of the state, especially throughout the north central portion, where structural materials are scarce. The principal products are building block, cement brick and drain tile. The industry is yet

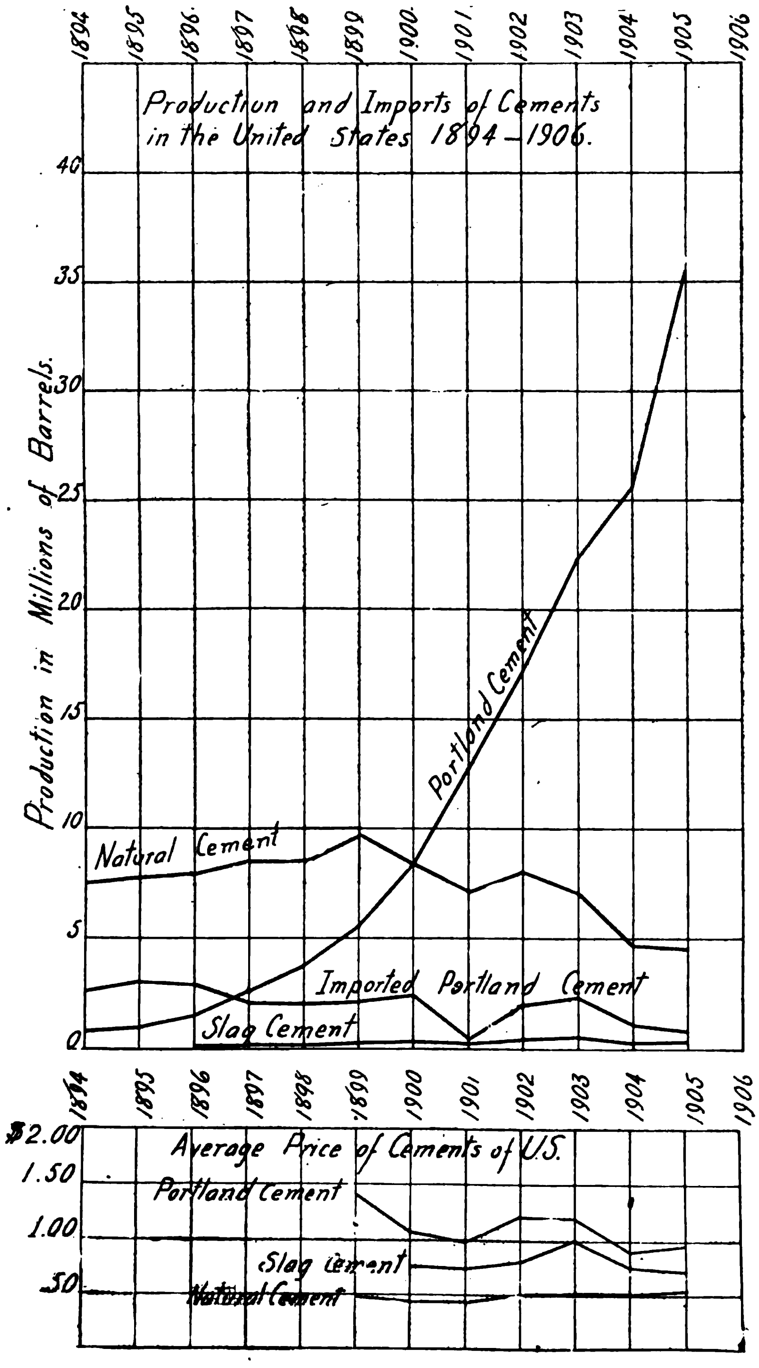


PLATE V.—Production, imports and prices of cements in the United States from 1894 to 1905.

in its infancy. The leading products marketed during the year were as follows:

Building block	$ 207,195
Cement brick	24,379
Drain tile	102,535
Fence posts	11,497
Roof tile	5,215
Total	$ 350,821

A much larger amount of cement was used in the building of sidewalks, floors, foundations, chimneys, water tanks and fireproofing.

QUARRY PRODUCTS
OF IOWA

S. W. BEYER
IRA A. WILLIAMS

MATERIALS AND MANUFACTURE
OF
PORTLAND CEMENT

BY

S. W. Beyer and Ira A. Williams

THE MATERIALS AND MANUFACTURE OF PORTLAND CEMENT

BY S. W. BEYER AND IRA A. WILLIAMS

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CHAPTER I

THE MATERIALS AND MANUFACTURE OF PORTLAND CEMENT.

The following general treatise on the properties of the raw materials and the processes of manufacture of Portland cement is taken largely from the report of Mr. E. C. Eckel, on Cement Materials of Iowa, Iowa Geological Survey, Volume XV. According to Eckel's grouping, the so-called Complex Cements only, are considered in this chapter. In order to indicate the relation existing between Portland and other complex cementing materials, a brief presentation is given of the characteristics of the more commonly used silicate cements.

COMPLEX CEMENTS.

The cementing materials grouped here as Silicate or Hydraulic Cements include all those materials whose setting properties are due to the formation of new compounds, during manufacture or use, and not to the mere reassumption of the original composition of the material from which the cement was made. These new compounds may be formed either by chemical change during manufacture or by chemical interaction, in use, of materials which have merely been mechanically mixed during manufacture.

In the class of silicate cements are included all the materials commonly known as cements by the engineer (natural cements, Portland cement, pozzuolanic cements), together with the hydraulic limes.

Though differing widely in raw material, methods of manufacture and properties, the silicate cements agree in two prominent features; they are all hydraulic (though in very different degree); and this property of hydraulicity is, in all, due largely or entirely to the formation of tri-calcic silicate ($3CaO.SiO_2$). Other silicates of lime as well as silico-aluminates, may also be formed; but they are relatively unimportant, except in certain of the natural cements and hydraulic limes where the lime-aluminates may be of greater importance than is here indicated. This will be recurred to in discussing the groups named.

The silicate cements are divisible, on technologic grounds, into four distinct classes. The basis for this division is given below. It will be seen that the first named of these classes (the pozzuolanic cements) differs from the other three very markedly, inasmuch as its raw materials are not calcined after mixture; while in the last three classes the raw materials are invariably calcined after mixture. The four classes differ somewhat in composition but more markedly in methods of manufacture and in the properties of the finished cements.

CLASSES OF SILICATE CEMENTS.

1. *Pozzuolanic or Puzzolan Cements;* produced by the mechanical mixture, without calcination, of slaked lime and a silico-aluminous material (the latter being usually a volcanic ash or blast-furnace slag).

2. *Hydraulic Limes;* produced by the calcination, at a temperature not much higher than that of decarbonation, of a siliceous limestone so high in lime carbonate that a considerable amount of free lime appears in the finished product. See Chapter II.

3. *Natural Cements;* produced by the calcination, at a temperature between those of decarbonation and clinkering, of a siliceous limestone (which may also carry notable amounts of alumina and of magnesium carbonate) in which the lime carbonate is so low, relative to the silica and alumina, that little or no free lime appears in the cement.

4. *Portland Cements;* produced by the calcination, at the temperature of semi-vitrefaction ("clinkering") of an artificial mixture of calcareous with silico-aluminous materials, in the proportion of about three parts of lime carbonate to one part of clayey material.

NATURAL CEMENTS.

Natural cements are produced by burning a naturally impure limestone, containing from fifteen to forty per cent of silica, alumina, and iron oxide. This burning takes place at a comparatively low temperature, about that of ordinary lime burning. The operation can therefore be carried on in a kiln closely resembling an ordinary lime kiln. During the burning the carbon dioxide of the limestone is almost entirely driven off, and the lime combines with the silica, alumina and iron oxide, forming a mass containing silicates, aluminates, and ferrites of lime. In case the original limestone contained much magnesium carbonate, the burned rock will also contain a corresponding amount of magnesia.

After burning, the burned mass will not slake if water be added. It is necessary, therefore, to grind it quite finely. After grinding, if the resulting powder (natural cement) be mixed with water it will harden rapidly. This hardening or setting will also take place under water. The natural cements differ from ordinary limes in two noticeable ways:

(1) The burned mass does not slake on the addition of water.

(2) After grinding, the powder has hydraulic properties, i. e., if properly prepared, it will set under water.

Natural cements are quite closely related to both hydraulic limes on the one hand, and Portland cement on the other, agreeing with both in the possession of hydraulic properties. They differ from hydraulic limes, however, in that the burned natural cement rock will not slake when water is poured on it.

The natural cements differ from Portland cements in the following important particulars:

(1) Natural cements are not made by burning carefully prepared and finely ground artificial mixtures, but by burning masses of natural rock.

(2) Natural cements, after burning and grinding, are usually yellow to brown in color and light in weight, their specific gravity being about 2.7 to 2.9; while Portland cement is commonly blue to gray in color and heavier, its specific gravity ranging from 3.0 to 3.2.

(3) Natural cements are always burned at a lower temperature than Portland, and commonly at a *much* lower temperature, the mass of rock in the kiln never being heated high enough to even approach the fusing or clinkering point.

(4) In use, natural cements set more rapidly than Portland cement, but do not attain such a high ultimate strength.

(5) In composition, while Portland cement is a definite product whose percentages of lime, silica, alumina and iron oxide vary only between narrow limits, various brands of natural cements will show very great differences in composition.

The material utilized for natural cement manufacture is invariably a clayey limestone, carrying from 13 to 35 per cent of clayey material, of which 10 to 22 per cent or so is silica, while alumina and iron oxide together may vary from 4 to 16 per cent. It is the presence of these clayey materials which gives the resulting cement its hydraulic properties. Stress is often carelessly or ignorantly laid on the fact that many of our best known natural cements carry large percentages of magnesia, but it should, at this date, be realized that magnesia (*in natural cements at least*) may be regarded as being almost exactly interchangeable with lime, so far as the hydraulic properties of the product are concerned. The presence of magnesium carbonate in a natural cement rock is then merely incidental, while the silica, alumina, and iron oxide are essential. The thirty per cent or so of magnesium carbonate which occurs in the cement rock of the Rosendale district, N. Y., could be replaced by an equal amount of lime carbonate, and the burnt stone would still give a hydraulic product. If, however, the clayey portion (silica, alumina, and iron oxide) of the Rosendale rock could be removed, leaving only the magnesium and lime carbonates, the burnt rock would lose all of its hydraulic properties and would yield simply a magnesian lime.

This point has been emphasized because many writers on the subject have either explicitly stated or implied that it is the magnesium carbonate of the Rosendale, Akron, Louisville, Utica and Milwaukee rocks that causes them to yield a natural cement on burning.

PORTLAND CEMENT.

Portland cement is produced by burning a finely ground, artificial mixture containing essentially lime, silica, alumina, and iron oxide, in certain definite proportions. Usually this combination is made by mixing limestone or marl with clay or shale, in which case about three times as much of the lime carbonate should be present in the mixture as of the clay materials. The burning takes place at a high temperature, approaching 3,000° F., and must therefore be carried on in kilns of special design and lining. During the burning, combination of the lime with silica, alumina, and iron oxide takes place. The product of the burning is a semi-fused mass called clinker, and consists of silicates, aluminates and ferrites of lime in certain definite proportions. This clinker must be finely ground. After such grinding the powder (Portland cement) will set under water.

As noted above, under the head of Natural Cements, Portland cement is blue to gray in color, with a specific gravity of 3.0 to 3.2, and sets more slowly than natural cements, but soon attains a higher tensile strength.

PUZZOLAN CEMENTS.

The cementing materials included under this name are made by mixing powdered slaked lime with either a volcanic ash or a blast-furnace slag. The product is therefore simply a mechanical mixture of two ingredients, as the mixture is not burned at any stage of the process. After mixing, the mixture is finely ground. The resulting powder (Puzzolan cement) will set under water.

Puzzolan cements are usually light bluish in color, and of lower specific gravity and less tensile strength than Portland cement. They are better adapted to use under water than to use in air.

PORTLAND CEMENT.

DEFINITION.

In the following section various possible raw materials for Portland cement manufacture will be taken up, and their relative suitability for such use will be discussed. In order that the statements there made may be clearly understood it will be necessary to preface this discussion by a brief explanation regarding the composition and constitution of Portland cement.

Use of term Portland.—While there is a general agreement of opinion as to what is understood by the term Portland cement, a few points of importance are still open questions. The definitions of the term given in specifications are in consequence often vague and unsatisfactory.

It is agreed that the cement mixture must consist essentially of lime, silica and alumina in proportions which can vary but slightly; and that this mixture must be burned at a temperature which will give a semi-fused product—a "clinker." These points must therefore be included in any satisfactory definition. The point regarding which there is a difference of opinion is whether or not cements made by burning a natural rock can be considered true Portlands. The question as to whether the definition of Portland cement should be drawn so as to include or exclude such products is evidently largely a matter of convention; but, unlike most conventional issues, the decision has very important practical consequences. The question at issue may be stated as follows:

If we make artificial mixture of the raw materials and a very high degree of burning the criteria on which to base our definition, we must in consequence of that decision exclude from the class of Portland cements certain well known products manufactured at several points in France and Belgium, by burning a natural rock, without artificial mixture, and at a considerably lower temperature than is attained in ordinary Portland cement practice. These "natural Portlands" of France and Belgium have always been considered Portland cements by the most critical authorities, though all agree that they are not particularly ***high grade*** Portlands. So that a definition, based upon the criteria above named, will of necessity exclude from our class of Portland cements some very meritorious products.

There is no doubt that in theory a rock could occur, containing lime, silica and alumina in such correct proportions as to give a good Portland cement on burning. Actually, however, such a perfect cement rock is of extremely rare occurrence. As above stated, certain brands of French and Belgian "Portland" cements are made from such natural rocks, without the addition of any other material; but these brands are not particularly high grade, and in the better Belgian cements the composition is corrected by the addition of other materials to the cement rock, before burning.

The following definition of Portland cement is of importance because of the large amount of cement which will be accepted annually under the specifications* in which it occurs. It is also of interest as being the nearest approach to an official government definition of the material that we have in this country.

> "By a Portland cement is meant the product obtained from the heating or calcining up to incipient fusion of intimate mixtures, either natural or artificial, of argillaceous with calcareous substances, the calcined product to contain at least 1.7 times as much of lime, by weight, as of the materials which give the lime its hydraulic properties, and to be finely pulverized after said calcination, and thereafter additions or substitutions for the purpose only of regulating certain properties of technical importance to be allowable to not exceeding 2 per cent of the calcined product."

It will be noted that this definition does not require pulverizing or artificial mixing of the materials prior to burning. It seems probable that the Belgian "natural Portlands" were kept in mind when these requirements were omitted. In dealing with American made cements, however, and the specifications in question are headed, "Specifications for American Portland cement," it is a serious error to omit these requirements. No true Portland cements are at present manufactured in America from natural mixtures, without pulverizing and artificially mixing the materials prior to burning. Several plants, however, have placed on the market so-called Portland cements made by grinding up together the underburned and overburned materials formed during the burning of natural cements. Several of these brands contain from 5 to 15 per cent of magnesia, and under no circumstances can they be considered true Portland cements.

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* Professional paper No. 28, Corps of Engineers, U. S. A., p. 30.

In view of the conditions above noted, the writer believes that the following definition will be found more satisfactory than the one above quoted.

Definition of Portland Cement.—Portland cement is an artificial product obtained by finely pulverizing the clinker produced by burning to semi-fusion an intimate mixture of finely ground calcareous and argillaceous material, this mixture consisting approximately of one part of silica and alumina to three parts of carbonate of lime (or an equivalent amount of lime oxide).

COMPOSITION AND CONSTITUTION.

Portland cements may be said to tend toward a composition approximating to pure tri-calcic silicate ($3CaO. SiO_2$) which would correspond to the proportion CaO 73.6 per cent, SiO_2 26.4 per cent. As can be seen, however, from the analyses quoted later, actual Portland cements as at present made differ in composition somewhat markedly from this. Alumina is always present in considerable quantity, forming with part of the lime, the dicalcic aluminate ($2CaO. Al_2O_3$). This would give, as stated by Newberry, for the general formula of a pure Portland—

$$x(3CaO.\ SiO_2)+y(2CaO.\ Al_3O_3).$$

But the composition is still further complicated by the presence of accidental impurities, or intentionally added ingredients. These last may be simply adulterants, or they may be added to serve some useful purpose. Calcium sulphate is a type of the latter class. It serves to retard the set of the cement, and, in small quantities, appears to have no injurious effect which would prohibit its use for this purpose. In dome kilns, sufficient sulphur trioxide is generally taken up by the cement from the fuel gases to obviate the necessity for the later addition of calcium sulphate, but in the rotary kiln its addition to the ground cement, in the form of either powdered gypsum or plaster of Paris, is a necessity.

Iron oxide, within reasonable limits, seems to act as a substitute for alumina, and the two may be calculated together. Magnesium carbonate is rarely entirely absent from limestone or clays, and magnesia is therefore almost invariably present in the finished cement. Though magnesia, when magnesium carbonate is burned at low temperature, is an active hydraulic material, it does not combine with silica or alumina at the clinkering heat employed in Portland cement manufacture. At the best it is an inert and valueless constituent in the cement; many regard it as positively detrimental in even small amounts, and because of this feeling manufcturers prefer to carry it as low as possible. Newberry has stated that in amounts of less than three and one-half per cent it is harmless, and American Portlands from the Lehigh district usually reach well up toward that limit. In European practice it is carried somewhat lower.

Raw Materials.

GENERAL CONSIDERATIONS.

For the purpose of the present chapter it will be sufficiently accurate to consider that a Portland cement mixture, when ready for burning, will consist of about seventy-five per cent of lime carbonate ($CaCO_3$) and twenty per cent of silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) together, the remaining five per cent including any magnesium carbonate, sulphur and alkalies that may be present.

The essential elements which enter into this mixture, lime, silica, alumina and iron, are all abundantly and widely distributed in nature, occurring in different forms in many kinds of rocks. It can therefore readily be seen that, theoretically, a satisfactory Portland cement mixture could be prepared by combining, in an almost infinite number of ways and proportions, many possible raw materials. Obviously, too, we might expect to find perfect gradations in the artificialness of the mixture, varying from one extreme where a natural rock of absolutely correct composition was used to the other extreme where two or more materials, in nearly equal amounts, are required to make a mixture of correct composition.

The almost infinite number of raw materials which are theoretically available are, however, reduced to a very few in practice under existing commercial conditions. The necessity for making the mixture as cheaply as possible rules out of consideration a large number of materials which would be considered available if chemical composition was the only thing to be taken into account. Some materials otherwise suitable are too scarce; some are too difficult to pulverize. In consequence, a comparatively few combinations of raw material are actually used in practice.

In certain localities deposits of argillaceous (clayey) limestone or "cement rock" occur, in which the lime, silica, alumina and iron oxide exist in so nearly the proper proportions that only a relatively small amount (about ten per cent or so) of other material is required in order to make a mixture of correct composition.

In the majority of plants, however, most or all of the necessary lime is furnished by one raw material, while the silica, alumina and iron oxide are largely or entirely derived from another raw material. The raw material which furnishes the lime is usually natural, a limestone, chalk or marl, but occasionally an artificial product is used, such as the chemically precipitated lime carbonate which results as waste from alkali manufacture. The silica, alumina and iron oxide of the mixture are usually derived from clays, shales or slates; but in a few plants blast-furnace slag is used as the silico-aluminous ingredient in the manufacture of true Portland cement.

The various combinations of raw materials which are at present used in the United States in the manufacture of Portland cement may be grouped under six heads. This grouping is as follows:

1. Argillaceous limestone (cement rock) and pure limestone.
2. Pure hard limestone and clay or shale.
3. Soft chalky limestone and clay.
4. Marl and clay.
5. Alkali waste and clay.
6. Slag and limestone.

Raw Materials Actually in Use.

ARGILLACEOUS LIMESTONE: CEMENT ROCK.

An argillaceous limestone containing approximately 75 per cent of lime carbonate and 20 per cent of clayey materials (silica, alumina and iron oxide) would, of course, be the ideal material for use in the manufacture of Portland cement, as such a rock would contain within itself in the proper proportions all the ingredients necessary for the manufacture of a good Portland. It would require the addition of no other material, but when burnt alone would give a good cement. This ideal cement material is, of course, never realized in practice, but certain deposits of argillaceous limestone approach the ideal composition very closely.

The most important of these argillaceous limestone or "cement rock" deposits is, at present, that which is so extensively utilized in Portland cement manufacture in the "Lehigh district" of Pennsylvania and New Jersey. This area still furnishes about two-thirds of all the Portland cement manufactured in the United States.

The analyses given in the following table are fairly representative of the materials employed in the Lehigh district. The first four analyses are of "cement rock"; the last two are of the purer limestone used for mixing with it.

Analyses of Lehigh district cement materials.

	Cement rock				Limestone	
Silica (SiO_2)	10.02	9.52	14.52	16.10	3.02	1.98
Alumina (Al_2O_3)	6.26	4.72	6.52	2.20	1.90	0.70
Iron oxide (Fe_2O_3)	.....	.....	.....	.....	.....	.....
Lime carbonate ($CaCO_3$)	78.65	80.71	73.52	76.23	92.05	95.19
Magnesium carbonate ($MgCO_3$)	4.71	4.92	4.69	3.54	3.04	2.03

"CEMENT ROCK" IN OTHER PARTS OF THE UNITED STATES.

Certain Portland cement plants, particularly in the western United States, are using combinations of materials closely similar to those in the Lehigh district. Analyses of the materials used at several of these plants are given in the following table:

Analyses of "cement rock" and limestone from the western United States.

	Utah		California		Colorado	
	Cemen trock	Limestone	Cement rock	Limestone	Cement rock	Limestone
Silica (SiO_2)	21.2	6.8	20.06	7.12	14.20	......
Alumina (Al_2O_3)	8.0	3.0	10.07	2.36	5.21	......
Iron oxide (Fe_2O_3)	.....	.....	3.39	1.16	1.73	......
Lime carbonate ($CaCO_3$)	62.08	89.8	63.40	87.70	75.10	.88.0
Magnesium carbonate ($MgCO_3$)	3.8	0.76	1.54	0.84	1.10	......

PURE HARD LIMESTONES.

A series of analyses of representative pure hard limestones, together with analyses of the clays or shales with which they are mixed, is given below:

Analyses of pure hard limestones and clayey materials.

	Limestones				Clays and shales			
Silica (SiO_2)	1.72	0.86	0.56	0.40	63.56	55.80	56.30	60.00
Alumina (Al_2O_3)	1.63	0.63	1.23	0.44	27.32	30.20	29.86	23.26
Iron oxide (Fe_2O_3)	6.59	1.03	0.29					4.32
Lime carbonate ($CaCO_3$)	90.58	97.06	97.23	97.99	3.60	2.54	.....	1.70
Magnesium carbonate ($MgCO_3$)	.....	.....	0.75	0.42	2.60	.....	.....	1.50

The first limestone analysis given in the above table represents a curious type, used in several plants in the Middle West. As will be noted, it is a relatively impure limestone, but its principal impurity is iron oxide. It contains 8.22 per cent of iron oxide and alumina, as compared with 1.72 per cent of silica; and therefore demands great care in the selection of a suitable high-silica clay to mix with it.

SOFT LIMESTONE: CHALK.

ORIGIN AND GENERAL CHARACTER.

Chalk, properly speaking, is a pure carbonate of lime, composed of the remains of the shells of minute organisms, among which those of foraminifera are especially prominent. The chalks and soft limestones discussed here agree, not only in having usually originated in this way, but also in being rather soft and therefore readily and cheaply crushed and pulverized. As Portland cement materials they are, therefore, almost ideal. One defect, however, which to a small extent counterbalances their obvious advantages is the fact that most of these soft, chalky limestones absorb water quite readily. A chalky limestone which in a dry season will not carry over two per cent of moisture as quarried, may in consequence of prolonged wet weather show as high as fifteen or twenty per cent of water. This difficulty can of course be avoided if care be taken in quarrying to avoid unnecessary exposure to water and, if necessary, to provide facilities for storing a supply of the raw materials during wet seasons.

COMPOSITION.

In composition these chalks, or "rotten limestones," vary from a rather pure calcium carbonate, low in both magnesia and clayey materials to an impure clayey limestone, requiring little additional clay to make it fit for use in Portland cement manufacture. Analyses quoted from various authors of a number of these chalky limestones are given in the table below, and will serve to show their range of composition.

Analyses of chalky limestones.

	Demopolis, Ala.	San Antonio, Tex.	Dallas, Tex.	White Cliffs, Ark.	Yankton, S. Dak.	Milton, N. Dak.
Silica (SiO_2)	12.13	5.77	23.55	7.97	8.20	9.15
Alumina (Al_2O_3)	4.17	2.14	1.50	1.09	7.07	4.80
Iron oxide (Fe_2O_3)	3.28					2.30
Lime carbonate ($CaCO_3$)	75.07	90.15	70.21	88.64	83.59	63.75
Magnesium carbon. ($MgCO_3$)	.92	.58	.58	.73	n. d.	1.25

FRESH WATER MARLS.

Marls, in the sense in which the term is used in the Portland cement industry, are incoherent limestones which have been deposited in the basins of existing or extinct lakes. So far as chemical composition is concerned, marls are practically pure limestones, being composed almost entirely of calcium carbonate. Physically, however, they differ greatly from the compact rocks which are commonly described as limestones, for the marls are granular, incoherent deposits. This curious physical character of marls is due to the conditions under which they have been deposited, and varies somewhat according to the particular conditions which governed their deposition in different localities.

COMPOSITION.

As shown by the analyses below, marls are usually very pure lime carbonates. They therefore require the addition of considerable clay to bring them up to the proper composition for a Portland cement mixture.

The marls are readily excavated, but necessarily carry a large percentage of water. The mixture, on this account, is commonly made in the wet way, which necessitates driving off a high percentage of water in the kilns. Analyses of typical marls and clays are given in the following tables:

Analyses of marls and clays used in cement plants.

	Marl			Clay		
Silica (SiO_2)	0.25	3.0	1.60	40.48	52.0	63.75
Alumina Al_2O_3)	.10	....	1.55	20.95	17.0	16.40
Iron oxide (Fe_2O_3)					5.0	6.35
Lime carbonate ($CaCO_3$)	94.39	93.0	88.9	25.80	20.0	4.0
Magnesium carbon. ($MgCO_3$)	.38	1.5	.94	.99	....	2.1

ALKALI WASTE.

A very large amount of waste material results from the process used at alkali works in the manufacture of caustic soda. This waste material is largely a precipitated form of calcium carbonate, and if it is sufficiently free from impurities, it furnishes a cheap source of lime for use in Portland cement manufacture.

The availability of alkali waste for this purpose depends largely on what process was used at the alkali plant. Leblanc process waste, for example, carries a very large percentage of sulphides, which prevents its use as a Portland cement material.

Waste resulting from the use of the ammonia process, on the other hand, is usually a very pure mass of lime, mostly in the form of carbonate, though a little lime hydrate is commonly present. As pyrite is not used in the ammonia process, its waste is usually low enough in sulphur to be used as a cement material. The waste may carry a low or a very high percentage of magnesia, according to the character of the limestone that has been used in the alkali plant. When a limestone low in magnesium carbonate has been used, the resulting waste is a very satisfactory Portland cement material.

The following analyses are fairly representative of the waste obtained at alkali plants using the ammonia process:

Analyses of alkali waste.

	1	2	3	4
Silica (SiO_2)	0.60	1.75	1.98	0.98
Alumina (Al_2O_3)	3.04	0.61	1.41	1.62
Iron oxide (Fe_2O_3)			1.38	
Lime (CaO)	53.33	50.60	48.29	50.40
Magnesia (MgO)	0.48	5.35	1.51	4.97
Alkalies (Na_2O, K_2O)	0.20	0.64	0.64	0.50
Sulphur trioxide (SO_3)	n. d.	n. d.	1.26	n. d.
Sulphur (S)	n. d.	0.10	n. d.	0.06
Carbon dioxide (CO_2)	42.43	41.70	39.60	n. d.
Water and organic matter	n. d.		3.80	n. d.

Of the analyses quoted in the preceding table, those in the first and third columns represent materials which are actually used in Portland cement manufacture in England and the United States. The alkali wastes whose analyses are given in the second and fourth columns are notably too high in magnesia to be advisable for such use.

BLAST FURNACE SLAG.

True Portland cements, which must be sharply distinguished from slag (or puzzolan) cements, can be made from mixtures which contain blast furnace slag as one ingredient. In this case the slag is intimately mixed with limestone and the mixture is finely powdered. It is then burned in kilns and the resulting clinker pulverized.

The slags from iron furnaces consist essentially of lime (CaO), silica (SiO_2) and alumina (Al_2O_3), though small percentages of iron oxide (FeO), magnesia (MgO) and sulphur (S), are commonly present. Slag may, therefore, be regarded as a very impure limestone or a very calcareous clay, from which the carbon dioxide has been driven off. Two plants in the United States are at present engaged in the manufacture of true Portland cement from slag.

The slag used at a German Portland cement plant has the following range in composition:

Composition of slag used in Portland cement manufacture.

Silica (SiO_2)	30.	to	35.
Alumina (Al_2O_3)	10.	"	14.
Iron Oxide (FeO)	0.2	"	1.2
Lime (CaO)	46.	"	49.
Magnesia (MgO)	0.5	"	3.5
Sulphur trioxide (SO_3)	0.2	"	0.6

CLAYS AND SHALES.

Clays are ultimately derived from the decay of older rocks, the finer particles resulting from this decay being carried off and deposited by streams along their channels, in lakes, or along parts of the sea coast or sea bottom as beds of clay. In chemical composition the clays are composed essentially of silica and alumina, though iron oxide is almost invariably present in more or less amount, while lime, magnesia, alkalies and sulphur are of frequent occurrence, though usually in small percentages.

Shales are clays which have become hardened by pressure. The so-called "fire clays" of the coal measures are usually shales, as are many of the other "clays" of commerce.

For use as Portland cement materials clays or shales should be as free as possible from gravel and sand, as the silica present as pebbles or grit is practically inert in the kiln unless ground more finely than is economically practicable. In composition they should not carry less than 55 per cent of silica, and preferably from 60 to 70 per cent. The alumina and iron oxide together should not amount to more than one-half the percentage of silica, and the composition will usually be better the nearer the ratio

$$Al_2O_3 + Fe_2O_3 = \frac{SiO_2}{3}, \text{ is approached.}$$

Nodules of lime carbonate, gypsum or pyrite, if present in any quantity, are undesirable; though the lime carbonate is not absolutely injurious. Magnesia and alkalies should be low, preferably not above three per cent.

SLATE.

Slate is, so far as origin is concerned, merely a form of shale in which a fine, even and parallel cleavage has been developed by pressure. In composition, therefore, it will vary exactly as do the shales, and so far as composition alone is concerned, slate would not be worthy of more attention, as a Portland cement material, than any other shale.

Commercial considerations in connection with the slate industry, however, make slate a very important possible source of cement material. Good roofing slate is a relatively scarce material, and commands a good price when found. In the preparation of roofing slate for the market so much material is lost during sawing, splitting, etc., that only about ten to twenty-five per cent of the amount quarried is salable as slate. The remaining seventy-five to ninety per cent is of no service to the slate miner. It is sent to the dump heap and is a continual source of trouble and expense. This very material, however, as can be seen from the analyses quoted below, is often admirable for use, in connection with limestone, in a Portland cement mixture. As it is a waste product, it could be obtained very cheaply by the cement manufacturer.

Composition of American roofing slates.

	Maximum	Average	Minimum
Silica (SiO_2)	68.62	60.64	54.05
Alumina (Al_2O_3)	24.71	18.05	9.77
Iron oxides (FeO, Fe_2O_3)	10.66	6.87	2.18
Lime (CaO)	5.23	1.54	....
Magnesia (MgO)	6.43	2.60	0.12
Alkalies (K_2O, Na_2O)	8.68	4.74	1.93
Ferrous sulphide (FeS_2)	....	0.38	....
Carbon dioxide (CO_2)	....	1.47	....
Water of combination	....	3.51	....
Moisture, below 110°C	....	0.62	....

Factors Determining the Value of Deposits of Cement Materials.

It seems desirable to give a somewhat detailed discussion of the factors which influence the value of limestone, marl or chalk or clay for Portland cement manufacture. Determining the possible value, for Portland cement manufacture, of a deposit of raw material is a complex problem, since the value depends upon a number of distinct factors, all of which must be given due consideration. The more important of these factors are:

(1) Chemical composition of the material.
(2) Physical character of the material.
(3) Amount of material available.
(4) Location of the deposit with respect to transportation routes.
(5) Location of the deposit with respect to fuel supplies.
(6) Location of the deposit with respect to markets.

METHODS AND COST OF EXCAVATION OF RAW MATERIALS.

The natural raw materials used at present in Portland cement manufacture are obtained by one of three methods,—(a) quarrying, (b) mining, and (c) dredging. When the cement manufacturer is given an opportunity to choose between these different methods of excavation, his choice will depend partly on the physical character of the material to be excavated and partly on the topographic and geologic conditions. Usually, however, there is no opportunity for a choice of methods, for in any given case one of the methods will be so evidently the only possible mode of handling the material as to leave no room for other considerations.

The three different methods of excavation will first be briefly considered, after which the cost of raw materials at the mill will be discussed.

Quarrying.—In the following pages the term "quarrying" will be used to cover all methods of obtaining raw materials from open excavations—quarries, cuts or pits—whether the material excavated be a limestone, a shale or a clay. Quarrying is the most natural and common method of excavating the raw materials for cement manufacture. If marl, which is usually worked by dredging, be excluded from consideration, it is probably within safe limits to say that 95 per cent of the raw materials used at American Portland cement plants are obtained by quarrying. If marls be included, the percentages excavated by the different methods would probably be about as follows: Quarrying, 88 per cent; dredging, 10 per cent; mining, 2 per cent.

In the majority of limestone quarries the material is blasted out and loaded by hand on cars or carts. In a few limestone quarries a steam shovel is employed to do the loading, and in shale quarries this use of the steam shovel is more frequent. In certain clay and shale pits, where the materials are of suitable character, the steam shovel does all the work, both excavating and loading the raw materials.

The rock is usually shipped to the mill as quarried without any treatment except sledging it to a convenient size for loading. At a few quarries, however, a crushing plant is installed at the quarry, and the rock is sent as crushed stone to the mill. A few plants also have installed their driers at the quarry, and dry the stone before shipping it to the mill. Except the saving of mill space thus attained, this practice seems to have little to commend it.

Mining.—The term "mining" will be used, in distinction from "quarrying," to cover methods of obtaining any kind of raw material by underground workings, through shafts or tunnels. Mining is, of course, rarely employed in excavating materials of such low value per ton as the raw materials for Portland cement manufacture. Occasionally, however, when a thin bed of limestone or shale is being worked, its dip will carry it under such a thickness of other strata as to make mining cheaper than stripping and quarrying, for that particular case.

Mining is considerably more expensive work than quarrying but there are a few advantages about it that serve to counterbalance the greater cost per ton of raw material. A mine can be worked steadily and economically in all kinds of weather, while an open cut or quarry is commonly in a more or less unworkable condition for about three months of the year. Material won by mining is, moreover, always dry and clean.

Dredging.—The term "dredging" will be here used to cover all methods of excavating soft, wet, raw materials. The fact that the materials are wet implies that the deposit occurs in a basin or depression; and this in turn, implies that the mill is probably located at a higher elevation than the deposit of raw material, thus necessitating up-hill transportation to the mill.

The only raw material for Portland cement manufacture that is extensively worked by dredging, in the United States, is marl. Occasionally the clay used is obtained from deposits overlain by more or less water; but this is rarely done except where the marl and clay are interbedded or associated in the same deposit.

A marl deposit, in addition to containing much water diffused throughout its mass, is usually covered by a more or less considerable depth of water. This will frequently require the partial draining of the basin in order to get tracks laid near enough to be of service.

In dredging marl the excavator is frequently mounted on a barge, which floats in a channel resulting from previous excavation. Occasionally, in deposits which either were originally covered by very little water or have been drained, the shovel is mounted on a car, running on tracks laid along the edge of the deposit.

The material brought up by the dredge may be transported to the mill in two different ways, the choice depending largely upon the manufacturing processes in use at the plant. At plants using dome or chamber kilns, or where the marl is to be dried before sending to the kiln, the excavated marl is usually loaded by the shovel on cars, and hauled to the mill by horse or steam power. At normal marl plants, using a very wet mixture, it is probable that the second method of transportation is more economical. This consists of dumping the marl from the excavator into tanks, adding sufficient water to make it flow readily, and pumping the fluid mixture to the mill in pipes.

COST OF RAW MATERIALS AT MILL.

The most natural way, perhaps, to express the cost of the raw materials delivered at the mill would be to state it as being so many cents per ton or cubic yard of raw material, and this is the method followed by quarrymen or miners in general. To the cement manufacturer, however, such an estimate is not so suitable as one based on the cost of raw materials per ton or barrel of finished cement.

In the case of hard and comparatively dry limestones or shales, it may be considered that the raw material loses 33⅓ per cent in weight on burning. Converting this relation into pounds of raw material and of clinker we find that 600 pounds of dry raw material will make about four hundred pounds of clinker. Allowing something for other losses in the process of manufacture, it is convenient and sufficiently accurate to estimate that 600 pounds of dry raw material will give one barrel of finished cement. These estimates must be increased if the raw materials carry any appreciable amount of water. Clays will frequently contain 15 per cent or more of water, while soft chalky limestones, if quarried during wet weather, may carry as high as 15 to more than 20 per cent. A Portland cement mixture composed of a pure chalky limestone and a clay might, therefore, average 10 to 20 per cent of water, and consequently about seven hundred pounds of such a mixture would be required to make one barrel of finished cement.

With marls the loss on drying and burning is much greater. Russell states* that according to determinations made by E. D. Campbell, one cubic foot of marl, as it usually occurs in the normal deposits, contains about forty-seven and one-half pounds of lime carbonate and forty-eight pounds of water. In making cement from a mixture of marl and clay, therefore, it would be necessary to figure on excavating and transporting more than one thousand pounds of raw material for every barrel of finished cement.

From the preceding notes it will be understood that the cost of raw materials at the mill, per barrel of cement, will vary not only with the cost of excavation but with the kind of materials in use.

In dealing with hard, dry materials, extracted from open quarries near the mills, the cost of mining raw materials may vary between eight cents and fifteen cents per barrel of cement. The lower figure named is probably about the lowest attainable with good management and under favorable natural conditions; the higher figure is probably a maximum for fairly careful management of a difficult quarry under eastern labor conditions. When it is necessary to mine the materials, the cost will be somewhat increased. Cement rock has been mined at a cost equivalent to ten cents per barrel of cement, but this figure is attained under particularly favorable conditions. The cost of mining and transportation may reach from this figure up to twenty cents per barrel.

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*22d Ann. Rept. U. S. Geol. Surv., pt. 3, p. 657.

With regard to wet marls and clays, it is difficult to give even an approximate estimate. It seems probable, however, when the dead weight handled is allowed for, that these soft materials will cost almost as much, delivered at the mill, per barrel of finished cement, as the hard dry limestones and shales.

Methods of Manufacture.

If, as in the present discussion, we exclude from consideration the so-called "natural Portlands," Portland cement may be regarded as being an artificial product, obtained by burning to semi-fusion an intimate mixture of pulverized materials, this mixture containing lime, silica and alumina, varying in proportion only within certain narrow limits; and by crushing finely the clinker resulting from this burning.

If this restricted definition of Portland cement be accepted, four points may be regarded as being of cardinal importance in its manufacture. These are:

(1) The cement mixture must be of the proper chemical composition.

(2) The materials of which it is composed must be carefully ground and intimately mixed before burning.

(3) The mixture must be burned at the proper temperature.

(4) After burning, the resulting clinker must be finely ground.

The first named of these points, the chemical composition of the mixture, can be more advantageously discussed after the other three points have been disposed of. The subjects will therefore be taken up in the following order:

Preparation of the mixture for the kiln.

Burning the mixture.
Grinding the clinker, addition of gypsum, etc.
Composition and properties of Portland cement.

PREPARATION OF THE MIXTURE FOR THE KILN.

The preparation of the mixture for the kiln involves the reduction of both of the raw materials to a very fine powder, and their intimate mixture. In practice the raw materials are usually crushed more or less finely, and then mixed, after which the final reduction to powder takes place. Two general methods of treatment, the dry and the wet, are in use at different plants. Unless the limy constituent of the mixture is a marl, already full of water, the dry method is almost invariably followed. This consists merely in keeping the materials in as dry a condition as possible throughout the entire process of crushing and mixing; and, if the raw materials originally contained a little moisture, they are dried before being powdered and mixed. In the wet method, on the other hand, the materials are powdered and mixed while in a very fluid state, containing sixty per cent or more of water.

Drying the raw materials.—With the exception of the marls and clays used in the wet method of manufacture, Portland cement materials are usually dried before grinding is commenced. This is necessary because the raw materials, as they come from the quarry, pit or mine, will almost invariably carry appreciable, though often very small, percentages of water, which greatly reduces the efficiency of most modern types of grinding mills, and tends to clog the discharge screens.

Percentage of water in raw materials.—The percentage of water thus carried by the crude raw material will depend largely on the character of the material; partly on the method of handling and storing it; and partly on weather conditions.

In the case of hard limestones, freshly quarried, the water will commonly range from ½ to 3 per cent, rarely reaching or exceeding the higher figure except in the very wet quarries or during the rainy season. Such limestones, comparatively dry when quarried, are frequently sent to the grinding mills without artificial drying.

With the soft, chalky limestones, which absorb water very rapidly, the percentage can usually be kept down to 5 per cent or less in dry weather; while prolonged wet weather may necessitate the handling at the mill of material carrying as high as 15 to 20 per cent of water.

The clays present a much more complicated case. In addition to the hygroscopic or mechanically-held water that they may contain, there is also always present a certain percentage of chemically combined water. The amount of hygroscopic water present will depend on the treatment and exposure of the clay; and may vary from 1 per cent or so in clays which have been stored and air dried to as high as 30 per cent in fresh clays. The chemically combined water will depend largely on the composition of the clay, and may vary from 5 to 12 per cent. The hygroscopic or mechanically-held water of clays can be driven off at a temperature of 212° F., while the chemically combined water is lost only at a low red heat. The total water, therefore, to be driven off from clays may range from 6 to 42 per cent, depending on the weather, the drainage of the clay pit, and the care taken in preventing unnecessary exposure to moisture of the excavated clay. The average total amount of moisture will probably be about 15 per cent.

In dealing with shales, the mechanically-held water will rarely rise above 10 per cent, and can commonly be kept well below that limit. An additional 2 to 7 per cent of water will be carried by any shale, in a state of chemical combination.

At a few plants marl is used, with clay, in a dry process. As noted elsewhere the marls, as excavated, carry usually about 50 per cent of water. This case presents a more difficult problem than do the other raw materials, because the vegetable matter usually present in marls is extremely retentive of water.

It will be seen, therefore, that cement materials may carry from one per cent to fifty per cent of water when they reach the mill. In a dry process it is necessary to remove practically all of this water before commencing the grinding of the materials. One reason for this is that fine pulverizing can not be economically or satisfactorily accomplished unless absolutely dry material is fed to the grinding machinery. Another reason, which is one of convenience rather than of necessity, is that the presence of water in the raw materials complicates the calculation of the cement mixture.

Methods and costs of drying.—The type of dryer commonly used in cement plants is a cylinder approximately five feet in diameter and forty feet or so in length, set at a slight inclination to the horizontal and rotating on bearings. The wet raw material is fed in at the upper end of the cylinder, and it moves gradually toward the lower end, under the influence of gravity, as the cylinder revolves. In many dryers angle irons are bolted to the interior in such a way as to lift and drop the raw material alternately, thus exposing it more completely to the action of the heated gases, and materially assisting in the drying process. The dried raw material falls from the lower end of the cylinder into an elevator boot, and is then carried to the grinding mills.

The drying cylinder is heated either by a separate furnace or by waste gases from the cement kilns. In either case the products of combustion are introduced into the cylinder at its lower end, are drawn through it, and escape up a stack set at the upper end of the dryer.

The dryer above described is the simplest, and is most commonly used. For handling the small percentages of water contained in most cement materials it is very efficient, but for dealing with high percentages of water, such as are encountered when marl is to be used in a dry process, it seems probable that double heating dryers will be found more economical. This type is exemplified by the Ruggles-Coles dryer. In this dryer a double cylinder is employed. The wet raw material is fed into the space between the inner and outer cylinders, while the heated gases pass first through the inner cylinder, and then, in a reverse direction, through the space between the inner and outer cylinders. This double heating type of dryer is employed in almost all of the slag cement plants in the United States, and is also in use in several Portland cement plants.

When vertical kilns were in use, drying floors and drying tunnels were extensively used, but at present they can be found in only a few plants, being everywhere else supplanted by the rotary dryers.

The cost of drying will depend on the cost of fuel, the percentage of water in the wet material and the type of dryer. Even under the most unfavorable conditions five pounds of water can be expected to be evaporated per pound of coal used, while a good dryer will usually evaporate seven or eight pounds of water per pound of coal.

GRINDING AND MIXING;
DRY METHODS.

Part, at least, of the grinding is usually accomplished before the drying, but for convenience the subjects have been separated in the present paper. Usually the limestone is sent through a crusher at the quarry or mill before being dried, and occasionally the raw material is further reduced in a Williams mill, etc., before drying, but the principal part of the reduction always takes place after the material has been dried.

After the two raw materials have been separately dried they may be mixed immediately, or each may be further reduced separately before mixing. Automatic mixers, of which many types are on the market, give a mixture in proportions determined upon from analysis of the materials.

The further reduction of the mixture is usually carried on in two stages, the material being ground to about thirty mesh in a ball mill, komminuter, Griffin mill, etc., and finally reduced in a tube mill. At a few plants, however, single stage reduction is practiced in Griffin or Huntington mills, while at the Edison plant at Stewartsville, New Jersey, the reduction is accomplished in a series of rollers.

The majority of plants use either the Griffin mill and tube mill or the ball and tube mills, and there is probably little difference in the cost of operating these two combinations. The ball mill has never been quite as much of a success as its companion, the tube mill, and has been replaced at several plants by the komminuter.

Fineness of mixture.—After its final reduction, and when ready for burning, the mixture will usually run from 90 to 95 per cent through a 100-mesh sieve. In the plants of the Lehigh district the mixture is rarely crushed as fine as when limestone and clay are used. Newberry* has pointed out in explanation for this that an argillaceous limestone (cement rock) mixed with a comparatively small quantity of purer limestone, as in the Lehigh plants, requires less thorough mixing and less fine grinding than when a mixture of limestone and clay (or marl and clay) is used, for even the coarser particles of argillaceous limestone will vary so little in chemical composition from the proper mixture as to affect the quality of the resulting cement but little, should either mixing or grinding be incompletely accomplished.

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*Twentieth Ann. Rept. U. S. Geol. Surv., pt. 6, p.545.

A very good example of typical Lehigh Valley grinding of raw material is afforded by a specimen* examined by Prof. E. D. Campbell. This sample of raw mixture ready for burning was furnished by one of the best of the eastern Pennsylvania cement plants. A mechanical analysis of it showed the following results:

	Mesh of Sieve		
	50	100	200
Per cent passing	96.9	85.6	72.4
Per cent residue	3.1	14.4	27.6

The material, therefore, is so coarsely ground that only a trifle over 85 per cent passes a 100-mesh sieve.

WET METHODS.

Wet methods of preparing Portland cement mixtures date back to the time when millstones and similar crude grinding contrivances were in use. With such imperfect machinery it was impossible to grind dry materials fine enough to give a good Portland cement mixture. The advent of good grinding machinery has practically driven out the wet methods of manufacture in this country, except in dealing with materials such as marls, which naturally carry a large percentage of water. One or two plants in the United States do, it is true, deliberately add water to a limestone-clay mixture; but the effect of this practice on the cost sheets of these remarkable plants is not encouraging.

In preparing cement mixtures from marl and clay, a few plants dry both materials before mixing. It seems probable that this practice will spread, for the wet method of mixture is inherently expensive. At present, however, almost all marl plants use wet methods of mixing, and it is therefore necessary to give some space to a discussion of such methods.

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*Jour. Amer. Chem. Soc., vol. 25, p. 1106.

Certain points regarding the location, physical condition, and chemical composition of the marls and clays used in such mixtures have important effects upon the cost of the wet process. As regards location, considered on a large scale, it must be borne in mind that marl deposits of workable size occur only in the Northern States and in Canada. In consequence the climate is unfavorable to continuous working throughout the year, for the marl is usually covered with water, and in winter it is difficult to secure the material. In a minor sense location is still an important factor, for marl deposits necessarily and invariably are found in depressions; and the mill must, therefore, just as necessarily, be located at a higher level than its source of raw material, which involves increased expense in transporting the raw material to the mill.

Glacial clays, which are usually employed in connection with marl, commonly carry a much larger proportion of sand and pebbles than do the sedimentary clays of more southerly regions.

The effect of the water carried by the marl has been previously noted. The material as excavated will consist approximately of equal weights of lime carbonate and of water. This, on the face of it, would seem to be bad enough as a business proposition; but we find that in practice more water is often added to permit the marl to be pumped to the mill.

On the arrival of the raw materials at the mill the clay is often dried, in order to simplify the calculation of the mixture. The reduction of the clay is commonly accomplished in a disintegrator or in edge-runner mills, after which the material is further reduced in a pug mill, sufficient water being here added to enable it to be pumped readily. It is then ready for mixture with the marl, which at some point in its course has been screened to remove stones, wood, etc., as far as possible. The slurry is further ground in pug mills or wet grinding mills of the disk type; while the final reduction takes place commonly in wet tube mills. The slurry, now containing 30 to 40 per cent of solid matter and 70 to 60 per cent of water, is pumped into storage tanks, where it is kept in constant agitation to avoid settling. Analyses of the slurry are taken at this point, and the mixture in the tanks is corrected if found to be of unsatisfactory composition. After standardizing, the slurry is pumped into the rotary kilns. Owing to the large percentage of water contained in the slurry the fuel consumption per barrel of finished cement is 30 to 50 per cent greater, and the output of each kiln correspondingly less than in the case of a dry mixture.

It may be of interest, for comparison with the above description of the wet process with rotary kilns, to insert a description of the semi-wet process as carried on a few years ago at the dome kiln plant of the Empire Portland Cement Company of Warners, N. Y. The plant has been remodeled since that date, but the processes formerly followed are still of interest, as they resulted in a high grade though expensive product.

At the Empire plant the marl and clay are obtained from a swamp about three-fourths of a mile from the mill. A revolving derrick with clam-shell bucket was employed for excavating the marl, while the clay was dug with shovels. The materials were taken to the works over a private narrow-gauge road, on cars carrying about three tons each, drawn by a small locomotive. At the mill the cars were hauled up an inclined track, by means of a cable and drum, to the mixing floor.

The clay was dried in the Cummer "salamander" driers, after which it was allowed to cool, and then carried to the mills. These mills were the Sturtevant "rock emery" type, and reduced the clay to a fine powder, in which condition it was fed, after being weighed, to the mixer. The marl was weighed and sent directly to the mixer, no preliminary treatment being necessary. The average charge was about 25 per cent clay and about 75 per cent marl.

The mixing was carried on in a mixing pan twelve feet in diameter, in which two large rolls, each about five feet in diameter and sixteen-inch face, ground and mixed the materials thoroughly. The mixture was then sampled and analyzed, after which it was carried by a belt conveyor to two pug mills, where the mixing was completed and the slurry formed into slabs about three feet long and four to five inches in width and height. These on issuing from the pug mill were cut into a number of sections so as to give bricks about six inches by four inches by four inches in size. The bricks were then placed on slats, which were loaded on rack cars and run into the drying tunnels. The tunnels were heated by waste gases from the kilns and required from twenty-four to thirty-six hours to dry the bricks.

After drying, the bricks were fed into dome kilns, twenty of which were in use, being charged with alternate layers of coke and slurry bricks. The coke charge for a kiln was about four or five tons and this produced twenty to twenty-six tons of clinker at each burning, thus giving a fuel consumption of about 20 per cent, as compared with the 40 per cent or so required in the rotary kilns using wet materials. From thirty-six to forty hours were required for burning the charge. After cooling, the clinker was shoveled out, picked over by hand, and reduced in a Blake crusher, Smidth ball mills, and Davidsen tube mills.

Composition of mixture.—The cement mixture ready for burning will commonly contain from 74 to 77.5 per cent of lime carbonate, or an equivalent proportion of lime oxide. Several analyses of actual cement mixtures are given in the following table. Analysis No. 1, with its relatively high percentage of magnesia, is fairly typical of Lehigh Valley practice. Analyses Nos. 2 and 3 show mixtures low in lime, while analysis No. 4 is probably the best proportion of the four, especially in regard to the ratio between silica and alumina plus iron. This ratio, for ordinary purposes, should be about 3:1, as the cement becomes quicker setting and lower in ultimate strength as the percentage of alumina increases. If the alumina percentage be carried too high, moreover, the mixture will give a fusible, sticky clinker when burned, causing trouble in the kilns.

Analyses of cement mixtures.

	1	2	3	4
Silica (SiO_2)	12.62	13.46	13.85	14.77
Alumina and Iron oxide($Al_2O_3 + Fe_2O_3$)	6.00	?	7.20	4.35
Carbonate of lime ($CaCO_3$)	75.46	73.66	73.93	76.84
Magnesium oxide (MgO)	2.65	?	?	1.74

BURNING THE MIXTURE.

After the cement mixture has been carefully prepared, as described in preceding pages, it must be burned with equal care.

In the early days of the industry a simple vertical kiln, much like that used for burning lime and natural cement, was used for burning the Portland cement mixture. These kilns, while fairly efficient so far as fuel consumption was concerned, were expensive in labor, and their daily output was small. In France and Germany they were soon supplanted by improved types, but still stationary and vertical, which gave very much lower fuel consumption. In America, however, where labor is expensive while fuel is comparatively cheap, an entirely different style of kiln has been evolved. This is the rotary kiln. With the exception of a very few of the older plants, which have retained vertical kilns, all American Portland cement plants are now equipped with rotary kilns.

The history of the gradual evolution of the rotary kiln is of great interest, but as the subject can not be taken up here, reference should be made to the papers cited below[*] in which details, accompanied often by illustrations of early types of rotary kilns, are given.

The design, construction and operation of the vertical stationary kilns of various types is discussed in many reports on Portland cement, the most satisfactory single paper being probably that referred to below.[†] As the subject is, in America at least, a matter simply of historical interest, no description of these kilns or their operation will be given in the present paper.

At present, practice in burning at the different American cement plants is rapidly approaching uniformity, though difference in materials, etc., will always prevent absolute uniformity from being reached. The kiln in which the material is burned is now almost invariably of the rotary type, the rotary process, which is essentially American in its development, being based upon the substitution of machines for hand labor wherever possible. A brief summary of the process will first be given, after which certain subjects of interest will be taken up in more detail.

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[*] Duryee, E., The first manufacture of Portland cement by the direct rotary kiln process. Engineering News, July 26, 1900.

Leslie, R. W., History of the Portland cement industry in the United States, 146 pages, Philadelphia, 1900.

Lewis, F. H., The American rotary kiln process for Portland cement: Cement Industry, pp. 188-199, New York, 1900.

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Stanger, W. H., and Blount, B., The rotary process of cement manufacture. Proc. Institute Civil Engineers, Vol. 145, pp. 44-136, 1901.

Editorial, The influence of the rotary kiln on the development of Portland cement manufacture in America. Engineering News, May 3, 1900.

[†] Stanger, W. H., and Blount, B., Gilbert, W., Candlot, E., and others (Discussion of the value, design and results obtained from various types of fixed kilns). Proc. Institute Civil Engineers, Vol. 145, pp. 44-48, 81-82, 95-100. 1901.

SUMMARY OF BURNING PROCESS.

As at present used, the rotary kiln is a steel cylinder from about six to eight feet in diameter; its length, for dry materials, has usually been sixty feet, but during the past year many eighty-foot, one hundred-foot and even longer, kilns are frequently employed.

This cylinder is set in a slightly inclined position, the inclination being approximately one-half inch to the foot. The kiln is lined, except near the upper end, with very resistant fire brick, to withstand both the high temperature to which its inner surface is subjected and also the destructive action of the molten clinker.

The cement mixture is fed in at the upper end of the kiln, while fuel (which may be either powdered coal, oil, or gas) is injected at its lower end. The kiln, which rests upon geared bearings, is slowly revolved about its axis. This revolution, in connection with the inclination at which the cylinder is set, gradually carries the cement mixture to the lower end of the kiln. In the course of this journey the intense heat generated by the burning fuel first drives off the water and carbon dioxide from the mixture, and then causes the lime, silica, alumina and iron to combine chemically to form the partially fused mass known as "cement clinker." This clinker drops out of the lower end of the kiln, is cooled so as to prevent injury to the grinding machinery, and is then sent to the grinding mills.

THEORETICAL FUEL REQUIREMENTS.

As a preliminary to a discussion of actual practice in the matter of fuel, it will be of interest to determine the heat units and fuel theoretically required in the manufacture of Portland cement from a dry mixture of normal composition.

In burning such a mixture to a clinker, practically all of the heat consumed in the operation will be that required for the dissociation of the lime carbonate present into lime oxide and carbon dioxide. Driving off the water of combination that is chemically held by the clay or shale, and decomposing any calcium sulphate (gypsum) that may be present in the raw materials, will require a small additional amount of heat. The amount required for these purposes is not accurately known, however, but is probably so small that it will be more or less entirely offset by the heat which will be liberated during the combination of the lime with the silica and alumina. We may, therefore, without sensible error, regard the total heat theoretically required for the production of a barrel of Portland cement as being that which is necessary for the dissociation of 450 pounds of lime carbonate. With coal of a thermal value of 13,500 B. T. U., burned with only the air supply demanded by theory, this dissociation will require 25½ pounds of coal per barrel of cement, a fuel consumption of only 6.6 per cent.

LOSSES OF HEAT IN PRACTICE.

In practice with the rotary kiln, however, there are a number of distinct sources of loss of heat, which result in a fuel consumption immensely greater than the theoretical requirements given above. The more important of these sources of loss are the following:

1. The kiln gases are discharged at a temperature much above that of the atmosphere, ranging from 300° F. to 2,000° F., according to the type of materials used and the length of the kiln.
2. The clinker is discharged at a temperature varying from 300° F. to 2,500° F., the range depending, as before, on materials and length of the kiln.
3. The air supply injected into the kiln is always greater, and usually very much greater, than that required for the perfect combustion of the fuel; and the available heating power of the fuel is thereby reduced.
4. Heat is lost by radiation from the ends and exposed surfaces of the kiln.
5. The mixture, in plants using a wet process, carries a high percentage of water, which must be driven off.

It is evident, therefore, that present-day working conditions serve to increase greatly the amount of fuel actually necessary for the production of a barrel of cement above that required by theory.

ACTUAL FUEL REQUIREMENTS AND OUTPUT.

Rotary kilns are nominally rated at a production of 200 barrels per day per kiln. Even on dry and easily clinkered materials and with good coal, however, such an output is not commonly attained. Normally a kiln working a dry mixture will produce from 160 to 180 barrels of cement per day of twenty-four hours. In doing this, if good coal is used its fuel consumption will commonly be from 120 to 140 pounds of coal per barrel of cement, though it may range as high as 160 pounds, and, on the other hand, has fallen as low as 90 pounds. An output of 175 barrels per day, with a coal consumption of 130 pounds per barrel, may therefore be considered as representing the results of fairly good practice on dry materials. In dealing with a wet mixture, which may carry anywhere from 30 to 70 per cent of water, the results are more variable, though always worse than with dry materials. In working a sixty-foot kiln on a wet material, the output may range from 80 to 140 barrels per day, with a fuel consumption of from 150 to 230 pounds per barrel. Using a longer kiln, partly drying the mixture, and utilizing waste heat, will of course improve these figures materially.

When the heavy Western oils are used for kiln fuel, it may be considered that one gallon of oil is equivalent in the kiln to about ten pounds of coal. The fuel consumption, using dry materials, will range between eleven and fourteen gallons of oil per barrel of cement; but the output per day is always somewhat less with oil fuel than where coal is used.

Natural gas in the kiln may be compared with good Pennsylvania coal by allowing about 20,000 to 30,000 cubic feet of gas as equivalent to a ton of coal. This estimate is, however, based upon too few data to be as close as those above given for oil or coal.

EFFECT OF COMPOSITION ON BURNING.

The differences in composition between Portland cement mixtures are very slight if compared, for example, with the differences between various natural cement rocks. But even such slight differences as do exist exercise a very appreciable effect on the burning of the mixture. Other things being equal, any increase in the percentage of lime in the mixture will necessitate a higher temperature in order to get an equally sound cement. A mixture which will give cement carrying 59 per cent of lime, for example, will require much less thorough burning than would a mixture designed to give a cement with 64 per cent of lime.

With equal lime percentages, the cement carrying high silica and low alumina and iron will require a higher temperature than if it were lower in silica and higher in alumina and iron. But, on the other hand, if the alumina and iron are carried too high, the clinker will ball up in the kiln, forming sticky and unmanageable masses.

CHARACTER OF KILN COAL.

The fuel most commonly used in modern rotary kiln practice is bituminous coal, pulverized very finely. Coal for this purpose should be high in volatile matter, and as low in ash and sulphur as possible. Rusell gives the following analyses of West Virginia and Pennsylvania coals used at present at various cement plants in Michigan:

Analyses of kiln coals.

	1	2	3	4
Fixed carbon	56.15	56.33	55.82	51.69
Volatile matter	35.41	35.26	39.37	39.52
Ash	6.36	7.06	3.81	6.13
Moisture	2.08	1.35	1.00	1.40
Sulphur	1.30	1.34	0.42	1.46

The coal as usually bought is either "slack" or "run of mine." In the latter case it is necessary to crush the lumps before proceeding further with the preparation of the coal, but with slack this preliminary crushing is not necessary, and the material can go directly to the dryer.

DRYING COAL.

Coal as bought may carry as high as 15 per cent of water in winter or wet season. Uusally it will run from 3 to 8 per cent. To secure good results from the crushing machinery it is necessary that this water should be driven off. For coal drying, as for the drying of raw materials, the rotary dryer seems best adapted to American conditions. It should be said, however, that in drying coal it is usually considered inadvisable to allow the products of combustion to pass through the cylinder in which the coal is being dried. This restriction serves to decrease slightly the possible economy of the dryer, but an evaporation of six to eight pounds of water per pound of fuel coal can still be counted on with any good dryer. The fuel cost of drying coal containing 8 per cent of moisture, allowing $2 per ton for the coal used as fuel, will therefore be about three to four cents per ton of dried product.

PULVERIZING COAL.

Though apparently brittle enough when in large lumps, coal is a difficult material to pulverize finely. For cement kiln use, the fineness of reduction is very variable. The finer the coal is pulverized the better results will be obtained from it in the kiln; and the poorer the quality of the coal the finer it is necessary to pulverize it. The fineness attained in practice may therefore vary from 85 per cent, through a 100-mesh sieve, to 95 per cent or more, through the same. At one plant a very poor but cheap coal is pulverized to pass 98 per cent through a 100-mesh sieve, and in consequence gives very good results in the kiln.

Coal pulverizing is usually carried on in two stages, the material being first crushed to 20 to 30-mesh in a Williams mill or ball mill, and finally reduced in a tube mill. At many plants, however, the entire reduction takes place in one stage, Griffin or Huntington mills being used.

TOTAL COST OF COAL PREPARATION.

The total cost of crushing (if necessary), drying and pulverizing coal, and of conveying and feeding the product to the kiln, together with fair allowances for replacements and repairs, and for interest on the plant, will probably range from about twenty to thirty cents per ton of dried coal, for a 4-kiln plant. This will be equivalent to a cost of from three to five cents per barrel of cement. While this may seem a heavy addition to the cost of cement manufacture, it should be remembered that careful drying and fine pulverizing enable the manufacturer to use much poorer—and therefore cheaper—grades of coal than could otherwise be utilized.

CLINKER GRINDING.

The power and machinery required for pulverizing the clinker at a Portland cement plant using the dry process of manufacture is very nearly the same as that required for pulverizing the raw materials for the same output. This may seem, at first sight, improbable, for Portland cement clinker is much harder to grind than any possible combination of raw materials; but it must be remembered that for every barrel of cement produced about 600 pounds of raw materials must be pulverized, while only a scant 400 pounds of clinker will be treated, and that the large crushers required for some raw materials can be dispensed with in crushing clinker. With this exception, the raw material side and the clinker side of a dry-process Portland cement plant are usually almost or exactly duplicates.

The difficulty, and in consequence the expense, of grinding clinker will depend in large part on the chemical composition of the clinker and on the temperature at which it has been burned. The difficulty of grinding, for example, increases with the percentage of lime carried by the clinker; and a clinker containing 64 per cent of lime will be very noticeably more resistant to pulverizing than one carrying 62 per cent of lime So far as regards burning, it may be said in general that the more thoroughly burned the clinker the more difficult it will be to grind, assuming that its chemical composition remains the same.

The tendency among engineers at present is to demand more finely ground cement. While this demand is doubtless justified by the results of comparative tests of finely and coarsely ground cements, it must be borne in mind that any increase in fineness of grinding means a decrease in the product per hour of the grinding mills employed, and a consequent increase in the cost of cement. At some point in the process, therefore, the gain in strength due to fineness of grinding will be counter-balanced by the increased cost of manufacturing the more finely ground product.

The increase in the required fineness has been gradual but steady during recent years. Most specifications now require at least 90 per cent to pass a 100-mesh sieve; a number require 92 per cent; while a few important specifications require 95 per cent. Within a few years it is probable that almost all specifications will go as high as this.

ADDITION OF GYPSUM.

The cement produced by the rotary kiln is invariably naturally so quick-setting as to require the addition of sulphate of lime. This substance, when added in quantities up to 2½ or 3 per cent, retards the rate of set of the cement proportionately, and appears to exert no injurious influence on the strength of the cement. In amounts above 3 per cent, however, its retarding influence seems to become at least doubtful, while a decided weakening of the cement is noticeable.

Sulphate of lime may be added in one of two forms, either as crude gypsum or as burned plaster. Crude gypsum is a natural hydrous lime sulphate, containing about 80 per cent of lime sulphate and 20 per cent of water. When gypsum is calcined at temperatures not exceeding 400° F., most of its contained water is driven off. The "plaster" remaining carries about 93 per cent of lime sulphate, with only 7 per cent of water.

In Portland cement manufacture either gypsum or burned plaster may be used to retard the set of the cement. As a matter of fact, gypsum is the form almost universally employed in the United States. This is merely a question of cost. It is true, that to secure the same amount of retardation of set it will be necessary to add a little more gypsum than if burned plaster were used; but, on the other hand, gypsum is much cheaper than burned plaster.

The addition of the gypsum to the clinker is usually made before it has passed into the ball mill, komminuter, or whatever mill is in use for preliminary grinding. Adding it at this point secures much more thorough mixing and pulverizing than if the mixture were made later in the process. At some of the few plants which use plaster instead of gypsum, the finely ground plaster is not added until the clinker has received its final grinding and is ready for storage or packing.

Constitution of Portland Cement.

During recent years much attention has been paid by various investigators to the constitution of Portland cement. The chemical composition of any particular sample can, of course, be readily determined by analysis, and by comparison of a number of such analyses, general statements can be framed as to the range in composition of good Portland cements.

The chemical analysis will determine what ingredients are present, and in what percentages, but other methods of investigation are necessary to ascertain in what manner these various ingredients are combined. A summary only of the more important results brought out by these investigations on the constitution of Portland cement will be given in this place.

It would seem to be firmly established that, in a well burned Portland cement, much of the lime is combined with most of the silica to form the compound 3 CaO. SiO_2, tricalcic silicate. To this compound are ascribed, in large measure, the hydraulic properties of the cement, and in general it may be said that the value of a Portland cement increases directly as the proportion of 3 CaO. SiO_2. The ideal Portland cement, toward which cements as actually made tend in composition, would consist exclusively of tricalcic silicate, and would be, therefore, composed entirely of lime and silica, in the following proportions:

Lime (CaO)	73.6
Silica (SiO_2)	26.4

Such an ideal cement, however, can not be manufactured under present commercial conditions, for the heat required to clinker such a mixture can not be attained in any working kiln. Newberry has prepared such mixtures by using the oxy-hydrogen blowpipe; and the electrical furnace will also give clinker of this composition; but a pure lime-silica Portland is not possible under present day conditions.

In order to prepare Portland cement in actual practice, therefore, it is necessary that some other ingredient or ingredients should be present to serve as a flux in aiding the combination of the lime and silica, and such aid is afforded by the presence of alumina and iron oxide.

Alumina (Al_2O_3) and iron oxide (Fe_2O_3), when present in noticeable percentages, serve to reduce the temperature at which combination of the lime and silica (to form 3 $CaO. SiO_2$) takes place; and this clinkering temperature becomes further and further lowered as the percentages of alumina and iron are increased. The strength and value of the product, however, also decrease as the alumina and iron increase; so that in actual practice it is necessary to strike a balance between the advantage of low clinkering temperature and the disadvantage of weak cement, and to thus determine how much alumina and iron should be used in the mixture. Alumina affects the initial setting of cement, high alumina producing rapid while low alumina produces slow setting. It is advisable to keep the alumina as low as possible, but high enough to secure a proper clinkering temperature. High alumina causes a fusible sticky clinker liable to ball up in the kiln. Le Chatelier considers the alumina compounds in Portland cement the cause of its disintegration by sea water, the action being as follows:

The hardening of cement liberates free lime which reacts with the magnesium sulphate always present in sea-water to form calcium sulphate. This in turn reacts with the calcium aluminate of the cement to form sulph-aluminate of lime, a compound that swells on hydration, thus disintegrating the whole mass.

It is generally considered that whatever alumina is present in the cement is combined with part of the lime to form the compound 2 $CaO. Al_2O_3$, dicalcic aluminate. It is also held by some, but this fact is somewhat less firmly established than the last, that the iron present is combined with the lime to form the compound 2 $CaO. Fe_2O_3$. Iron oxide in less amounts than 4 to 6 per cent is usually calculated as alumina, but if more is present, the difference in their combining weights must be allowed for. It decreases the clinkering temperature but differs from alumina in giving a slower setting cement. The darker colors of cements are usually produced by the iron oxide contained.

The European limit for magnesia is 3 per cent but good Portlands are made in the Lehigh Valley region with 4 to 5 per cent. Professor S. B. Newberry has proved that good cements can be made carrying 10 per cent magnesia if due care be exercised in mixing and burning. Magnesia is regarded by some as equivalent in its behavior to lime and within limits it can be used to replace the latter if allowance be made for the difference in their combining weights. It is theoretically possible to prepare a series of lime-magnesia cements parallel to Portland cements as now made. These will differ in quality and behavior and would not be properly classified with Portlands. The amount of magnesia in Portland cement is now generally restricted to less than 5 per cent. Its detrimental effect takes place after the calcium compounds have hydrated and thus causes expansion which tends to destroy the structure of the cement.

Sulphur may occur as sulphate or sulphide. In the rotary kiln, the usual oxidizing flame dissociates sulphates as follows: $CaSO_4 + \text{heat} = CaO + SO_3$. The SO_3 passes off as gas. If the flame is not sufficiently oxidizing, the $CaSO_4$ may be reduced to sulphide form.

Alkalies in small per cents have been considered detrimental by some, inert or beneficial by others, but their effect is not well known. The rate of setting is hastened by addition of alkali solutions. Most of the alkali in the raw mixture is probably volatilized during the burning and would form a valuable by-product if recovered from the flue gases.

Phosphorus is seldom found in cement materials except marl. Its effect on cement is not definitely known, but is supposed to cause an increase in the tensile strength at first but a loss when the cement is older.

TESTING OF RAW MATERIALS TO DETERMINE AVAILABILITY FOR THE MANUFACTURE OF PORTLAND CEMENT.

As is pointed out in preceding paragraphs, the natural deposits from which Portland cement is made comprise limestone, chalk or marl and clay or shale. In the exploitation of these raw materials there are a number of factors to be taken into consideration. The more important of these are enumerated on page 50. Whether given beds are suitable, depends primarily on their chemical composition and physical characteristics. Should these properties prove favorable, the extent of the deposits, that is, the quantity of the raw materials available, must be ascertained, before the strictly commercial and economic relations, transportation facilities, fuel supply and markets, are brought under serious consideration.

Evidently, the location of the proper materials is the first step in exploitation. At the same time, the commercial factors must be kept in mind, for it would be useless to prospect for cement-making materials, as for any other economic product, in regions which, because of their remoteness, preclude utilization or development. Recalling, however, the fact that Portland cement requires limestone and clay in about the proportion of 3 to 1, it is apparent that both ingredients need not be found in immediate proximity to each other. It is not unusual for cement plants to locate at the source of the lime, the clay or shale being transported for considerable distances. Suitable limestone, therefore, is the first essential, after which a clay or shale must be found that will give a proper cement mixture in combination with the limestone.

It is rarely, if ever, the case that investigators are equipped with the necessary apparatus for making practical tests of favorable materials. Such tests would include fine grinding, mixing and burning to clinker, besides pulverization of the burned cement and testing the setting properties of the product. In fact, there are few laboratories in this country where tests of this nature are carried out. Investigations of Portland cement materials have, up to the present, been limited substantially to chemical and physical tests of the separate raw ingredients, drawing conclusions from these as to their suitability; the final and only absolutely conclusive test being performed on a large scale in the completely equipped factory.

It has proven a problem of some magnitude to devise equipment with which can be imitated on a small scale the conditions to which cement materials are subjected in the factory. Burning tests have been especially troublesome, the designing of a small kiln in which the conditions could be accurately controlled and the necessary elevated temperatures produced, meeting with varying degrees of success.

It is, without doubt, due to the difficulties encountered in making the practical tests that more attention has been given to indirect methods of experiment. Experience has shown that not only must the limestone and shale be blended in certain proportions but that the various elements in the shale, especially, must be present in amounts bearing definite relations to each other or the proper mixture with the limestone is impossible. These factors depend alone on chemical composition. But the physical condition of the mineral particles composing the clay, and the limestone, if it be impure, is of equal importance. Of two clays with identical ultimate chemical composition, one might be eminently suitable and the second much less so or even valueless for making cement, on account of their dissimilar physical make-up.

In general, the finer the grain of the clay and of the impurities in the source of the lime, the more favorable are the materials for cement purposes. Size of grain is not, however, the only physical factor to be taken into account. Since the burning of cement brings about a chemical union of the lime with the silica, alumina and iron, the susceptibility of these latter compounds to the attack of the lime is of great importance. Free silica in the shape of crystalline quartz sand if very fine, is readily attacked at high temperatures. If the silica be present, however, in the non-crystalline or colloid condition, or in combination with alkalis or alkaline earths as in the feldspars, or with alumina as in clay itself, the size of grain may be considerably larger and chemical combination in burning proceed with equal facility. Silica or silicates which are thus susceptible to the action of caustic lime are said to be "unlocked," and the silica in a semi-nascent condition. Silica is the most important ingredient to be considered in this connection, but similar statements will apply in some degree to the iron oxide and alumina as well.

The chemical stability of the elements in the mixture should therefore be taken into account along with the size of grain, and the first factor may properly be referred to as a chemico-physical one.

The foregoing statements may perhaps suggest two principal lines of investigation to be applied to possible cement materials.

First, the ultimate chemical analysis of both classes of ingredients, the limestone or marl and the clay; second, an inquiry into, or a determination of, the susceptibility to attack by lime of the clay and other siliceous components. These two lines of procedure have been attempted, supplemented in some instances by actual burning tests. In the remaining portions of this chapter the methods employed are explained and some results are given.

Methods of Testing.

As has been shown, chemical composition is the necessary basis for scientific cement manufacture. A statement of the chemical analysis of each of the ingredients is essential in order that proper and uniform mixtures may be compounded. All experimental work to determine the value of cement materials must, as well, depend on a correct knowledge of the elements composing them. The chemical analysis affords a means of comparison of promising new materials with others now in use.

THE ANALYSIS OF LIMESTONES.*

The constituents to be determined are the insoluble siliceous matter, oxide of iron and aluminum, carbonate of lime and carbonate of magnesia. The siliceous matter consists of sand (silica) and silicates, chiefly clay (silicate of alumina).

Process of Analysis.—Weigh 1g. of the finely ground sample. Transfer it to a 4-in. casserole or dish, cover with a watch glass, add 25 to 30 c.c. of water, then 15 c.c. of concentrated HCl, and warm until all effervescence has ceased. Remove the cover, wash it off into the dish, add 4 to 5 drops of HNO_3 and evaporate the solution to dryness on a water bath or hot plate; or replace the cover and boil down directly over the lamp, using constant care to prevent loss by "spattering"; finally heat very carefully over the lamp flame until all odor of HCl is gone. The temperature attained should not exceed 120° C. It can be regulated by drying in an air bath, but the "trick" of doing it as indicated is soon learned and saves much time. Now cool, add 5 c.c. of HCl, warm till the Fe salts are dissolved, add 50 c.c. of water and heat until everything dissolves except the siliceous matter, which forms a flocculent or sandy residue. Filter through a 5 or 7 cm. filter, and wash thoroughly with hot water until a few drops of the washings show no reaction for HCl when tested with $AgNO_3$.

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*Notes on Metallurgical Analysis, N. W. Lord. 2d Ed., 1903, p. 16.

Ignite and weigh the residue, which, after deducting the weight of the filter ash, constitutes the "insoluble siliceous matter." Keep it for the determination of the silica by fusion.

To the filtrate, the volume of which should be about 100 c.c., carefully add NH_4OH until it just smells distinctly of NH_3. Should the precipitate be light colored and large in amount, indicating the probable precipitation of $Mg(OH)_2$, add 5 c.c. HCl and again NH_4OH as before. Now boil the liquid about five minutes or until the odor of NH_3 has nearly gone—maintaining the volume of the liquid if necessary by adding water from time to time. Remove the lamp, and let the precipitate settle, filter into a small filter, wash well with hot water, ignite and weigh the precipitate of $Fe_2O_3 + Al_2O_3 + P_2O_5$.

The Fe_2O_3 and P_2O_5 may be determined in another portion, and when deducted from the above will give the alumina by difference.

Dilute the filtrate to about 200 c.c. If it is not distinctly alkaline add five to ten drops of NH_4OH, heat to boiling and slowly add 80 c.c. of a solution of $(NH_4)_2\ C_2O_4$ heated to boiling point also. Use a saturated solution of the salt diluted with an equal volume of water. Stir well during the addition of the reagent and for a minute or two afterwards, then set aside until the precipitate of CaC_2O_4 has settled completely. Decant the liquid through a 9 cm. filter without disturbing the precipitate, wash the precipitate once or twice by decantation, using about 100 c.c. of boiling water each time, then transfer it to the filter and wash 6 or 7 times with hot water. When the filtrate is to be concentrated for the determination of the magnesia, set aside the first filtrate and decantation and catch the subsequent washings in a separate beaker. Concentrate these by boiling down to a small volume and then add them to the first portion.

Dry the precipitate thoroughly, detach it as far as possible from the filter, put it in a weighed No. 0 porcelain crucible, burn the filter carefully on a platinum wire and add the ash to contents of the crucible. Now drop concentrated H_2SO_4 on to the precipitate till it is well moistened, but avoid much excess.

Heat the crucible (working under a "hood" to carry off the fumes) holding the burner in the hand and applying the flame cautiously until the swelling of the mass subsides, and the excess of H_2SO_4 has been driven off as white fumes. Finally heat to a cherry red for 5 minutes. Do not use the blast lamp. Cool and weigh the $CaSO_4$. The weight of the $CaSO_4$ multiplied by 0.735 gives the amount of $CaCO_3$ in the sample. The filtrate from the CaC_2O_4 should be, if over that volume, concentrated by boiling to 300 c.c.; should any MgC_2O_4 separate, dissolve it by adding a little HCl. Cool, add NH_4OH till alkaline, then add 10 c.c. or a sufficient quantity of a saturated solution of Na_2HPO_4. Then add gradually 1-10 of the volume of the liquid of strong NH_4OH, (sp. gr. 0.90) stir hard for some time, cover and let settle until the liquid is perfectly clear (about 2 hours), filter and wash with water containing 1-10 of its volume of strong NH_4OH and a little NH_4NO_3. Ten c.c. of the phosphate solution is sufficient for about 20 per cent of $MgCO_3$; for dolomites more must be added. Dry the precipitate, detach it from the filter and burn the filter on a platinum wire; now ignite precipitate and filter ash in a porcelain crucible, first heating carefully over a Bunsen burner till all volatile matter is driven off and it has been at a dull red heat for some minutes, then finishing over the blast lamp for five or ten minutes.

The ignited precipitate is $Mg_2P_2O_7$, the weight of which multiplied by 0.757 gives the $MgCO_3$ in the sample.

Treatment of the Siliceous Residue for the Determination of SiO_2.—Mix the ignited residue with eight or ten times its weight of dry Na_2CO_3, in a platinum crucible of at least 15 c.c. capacity, heat it over a Bunsen burner until the mass has well caked together, then over a blast lamp until it is in quiet fusion. Now remove the crucible with a pair of tongs and dip the bottom in cold water, which will usually cause the mass to loosen.

Wash off any of the material spattered on the cover of the crucible into a casserole with hot water. Add the fused cake, if it has come loose; if not, fill the crucible with water and warm until the fused mass softens up and can be transferred to the casserole. Finally clean the crucible with hot water and add the washings. If any material adheres so as not to be removed by washing with water, dissolve it with a little HCl and add to the rest, (on no account punch or dig the material out, as this may ruin the crucible). When the fusion has been thoroughly disintegrated by the hot water and no hard lumps are left, add HCl until everything dissolves, cover the dish and warm till effervescence ceases. Remove and wash the cover and evaporate the solution to dryness on a water bath or otherwise; when dry and every trace of odor of HCl has gone, add 10 c.c. dilute HCl (1 : 1) and then 50 c.c. of water. Warm till the NaCl has dissolved, filter, wash well with hot water, dry and ignite the residual SiO_2. The ignition must be repeated and the residue reweighed until its weight does not change.

In the filtrate the iron, alumina, lime and magnesia may be determined as in the regular process, and the amounts so found added to the weight of the main precipitates.

THE ANALYSIS OF CLAYS.*

Fuse 1 gram of the finely ground clay, dried at 100° C., with 10 grams of sodium carbonate and a very little sodium nitrate. Run the fused mass well up on the sides of the crucible, allow it to cool, and treat it with hot water until thoroughly disintegrated, transferring the liquid from time to time to a platinum dish. Treat the crucible with hydrochloric acid, add this to the liquid in the dish, acidulate with hydrochloric acid, and evaporate to dryness in the air-bath. Treat the mass with water and a little hydrochloric acid, evaporate again to dryness, and treat with 15 c.c. hydrochloric acid and 45 c.c. water. Allow it to stand in a warm place for fifteen or twenty minutes, add 50 c.c. water, and stand in a warm place for fifteen or twenty minutes, add 50 c.c. water, and filter on an ashless filter. Wash thoroughly with hot water acidulated with a few drops of hydrochloric acid, dry, ignite, heat for three or four minutes over the blast-lamp, and weigh. Treat the precipitate with hydrofluoric acid and a few drops of sulphuric acid, evaporate to dryness, ignite, and weigh. The difference between the two weights is silica. If any appreciable residue remains in the crucible, treat it with a little hydrochloric acid, and wash it out into the filtrate from the silica. Transfer the filtrate from the silica to a large platinum dish, heat it to boiling, add an excess of ammonia, boil until the smell of ammonia is quite faint, filter on an ashless filter, and wash several times with hot water. Stand the filtrate and washings aside, and treat the precipitate on the filter with a mixture of 15 c.c. hydrochloric acid and 15 c.c. water (cold). Allow the solution to run into a small clean beaker, replace this by the platinum dish in which the precipitation was made, pour the solution on the filter again, and repeat this operation until the precipitate has completely dissolved. Rinse the beaker and wash the filter thoroughly with cold water, dry, and preserve it. Reprecipitate by ammonia, as above directed, filter on an ashless filter, wipe the dish with small pieces of filter-paper, add these to the precipitate, and wash thoroughly with hot water. Dry, ignite and precipitate and filter, and the filter from the first precipitation, heat for a few minutes over the blast-lamp, cool, and weigh as alumina and ferric oxide. Fuse the ignited precipitate with sodium carbonate, treat the fused mass with water, wash it into a small beaker, allow the residue to settle, decant off the clear, supernatant fluid, treat the residue with hydrochloric acid, and determine the iron volumetrically, or add citric acid and ammonia, and after precipitating the iron as sulphide, filter, wash, dissolve in hydrochloric acid, oxidize with bromine-water, and precipitate the ferric oxide by ammonia. Filter, wash, dry, ignite, and weigh as ferric oxide. Subtract the weight of ferric oxide from the alumina plus ferric oxide found above, and the difference is alumina.

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* Blair's Chemical Analysis Iron, 6th Ed. 1906, p. 278.

As the amounts of calcium and magnesium in clay are very small, the filtrate and washings from the second precipitation of alumina plus ferric oxide may be rejected and the lime and magnesia determined in the first filtrate as directed on page 77.

The J. Lawrence Smith process is standard for determining alkalis. Place 1 gram of the finely ground clay in a porcelain or agate mortar, add an equal weight of granular ammonium chloride, and grind the entire mass so as to obtain an intimate mixture of the whole. Transfer to a capacious platinum crucible, cover with a close-fitting lid, and heat carefully to decompose the ammonium chloride, which is accomplished in a few minutes. Heat gradually to redness, and keep the bottom of the crucible at a bright red for about an hour. Allow the crucible to cool, and if the mass is easily detached from the crucible, transfer it to a platinum dish and add about 80 c.c. of water. Wash the crucible and lid with boiling water, pouring washings into the dish. Heat the water in the dish to boiling, and, when the mass has completely slaked, filter into another platinum dish and wash the mass on the filter with hot water. If the semi-fused mass in the crucible is not easily detached, place the crucible on its side in the dish, add about 100 c.c. water, and heat until the mass disintegrates. Remove the crucible, rinse it, and filter as above directed. To the filtrate add about 1 ½ grams of pure ammonium carbonate, evaporate on the water-bath, or very carefully over a light, until the volume of the solution is reduced to about 40 c.c., add a little more ammonium carbonate and a few drops of ammonia, and filter on a small filter. Evaporate the filtrate carefully after adding a few drops more of ammonium carbonate to make certain that all the lime has been precipitated. If any further precipitate appears, filter into a platinum crucible and evaporate to dryness. Heat carefully to dull redness to drive off any ammonium salts, and weigh the residue as potassium sodium chloride. To the residue in the crucible add a little water, in which the residue should dissolve perfectly, and a solution of platinic chloride. Evaporate down in the water-bath until the mass in the crucible solidifies upon cooling, add a little water to dissolve the excess of platinic chloride, and then an equal volume of alcohol.[*] Filter on a Gooch crucible, wash with alcohol until the filtrate runs through perfectly colorless, dry at 120° C., and weigh as potassium platinic chloride. This weight, multiplied by .19395, gives the weight of potash. Then multiply the weight of potassium platinic chloride by .30696, which gives the weight of potassium chloride. Subtract this from the weight of potassium chloride plus sodium chloride previously obtained, and the difference is the weight of sodium chloride which, multiplied by .53077, gives the weight of soda.

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[*] The strength of the alcohol is important. The K_2PtCl_6 is practically insoluble in 80 per cent alcohol, but the Na_2PtCl_6 will dissolve in it. Time must be given to secure complete solution of this latter salt. Lord's Metallurgical Notes, Ed. 1903, p. 208.

Determine the water of composition by igniting 1 gram of the clay for twenty minutes at a bright red heat, when the loss of weight will represent the water.

INTERPRETATION OF ANALYSES.

The point in an analysis of a clay to which attention should first be given is the relation between the percentage of silica and the sum of the alumina and the iron oxide. Experience has shown that,

$$\frac{SiO_2}{Al_2O_3 + Fe_2O_3} \text{ should be } < 3.57 \text{ and } > 2.0,$$

in order that a proper mixture may be made with a pure limestone. The magnesia must not run over 5 to 6 per cent. The allowable maximum of alkalis and sulphur is 3 per cent. Texturally the clay should be fine-grained, and contain less than one per cent of free silica as sand or chert, since particles larger than 150-mesh will not easily enter into combination with lime.

So far as the complete chemical analysis tells us, we learn nothing of the state of combination in which any of the oxides determined exist. It is especially necessary to know whether the silica is present in available condition to combine with lime in burning. The decomposition of silicates by heating with lime carbonate to a red heat is practiced in quantitative analysis in the determination of alkalis in silicates by the J. L. Smith process. This principle has been applied by Professor Lunge and Dr. Schochor in Germany in the investigation of marls for cement manufacture. They showed that lime attacks most readily the combined silica and that present in a fine state of division, and that an expression of the cement-making value of the marls might be thus obtained. Professor Edward Orton, Jr., has applied the same process to the investigation of clays* by which means a value is obtained which may be termed the hydraulic factor. In Orton's work a fixed proportion of one part clay to four of pure $CaCO_3$ was employed and the mixture heated to 1100° C. for seventy-five minutes. The latter method with slight modifications has been used to test Iowa clays.

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* Bulletin No. 3, Ohio Geological Survey, p. 120 et seq.

It is evident that the knowledge gained from both the complete and the carbonate analysis is of much greater value than the results of either alone. So far as used, the Orton method is regarded as furnishing the most reliable obtainable data as to the availability of a clay, without an actual burning test. Practical application has not yet proven that clays which appear unfavorable under this treatment will be unsuitable as a cement material. A wider use will be required to demonstrate this point. It is known, however, that some clays that have tested favorably by the method have proved satisfactory in practice.

The tests made by the Ohio Geological Survey and the present experiments indicate that there is an intimate relation between the chemical and physical condition of the minerals composing clays and the value of the latter for cement manufacture. The carbonate analysis seems the most satisfactory means yet suggested of expressing this relation.

DETERMINATION OF HYDRAULIC FACTOR.

The clay to be tested was crushed to one-eighth inch in a small roll-jaw crusher. One hundred grams were weighed approximately and disintegrated by boiling. The sample was then put on a 40-mesh sieve. The over size was intimately mixed with that passing through the sieve before the sample for burning was taken. As it is essential that the natural grain of the clay be not altered, no pulverizing was done, except such as was necessary to break the lumps before screening, and this only with the fingers or by boiling and rubbing with a soft rubber pestle.

Two grams of the prepared clay were weighed on a watch glass and enough calcium carbonate added to make a mixture of one part clay to four parts $CaCO_3$. Absolutely exact proportions are found not to be necessary, so long as there is an excess of the carbonate. One to four is found ample, and in order to give the clays uniform and comparable treatment was adhered to throughout. Allowance was therefore made for the lime which is practically always present in clays in greater or less quantity. To illustrate the method of making this correction, suppose a clay contains five per cent $CaCO_3$. Two grams contain 0.1 g. of the carbonate.

2.0 — 0.1 = 1.9 grams of the other clay ingredients present.
1.9 × 4 = 7.6 grams of $CaCO_3$ required to make a 1 to 4 mixture.
7.6 — 0.1 = 7.5 grams of $CaCO_3$ required to add to 2 grams of the clay to make the desired mixture.

The calcium carbonate and clay were well mixed on glazed paper and placed in a 50 c.c. platinum crucible. Enough water was added to make a thin slip which was stirred and the mass evaporated to dryness. The burning was done over a blast lamp in a small cylindrical furnace of the Erdman type. It was found inconvenient to maintain as high a heat (1100° C.) as recommended by the Ohio Geological Survey. The temperature employed varied from 950° C. to 1060° C. and the heating continued for seventy minutes after the maximum temperature was reached.

The temperature to be used in the test should be sufficiently high to bring into soluble form the maximum amount of silicate and yet remain safely below the limit where sintering or actual clinkering begins. In the subsequent treatment with acid and alkali the mass should disintegrate completely, which would not be the case had chemical combination progressed to the fusing or slag stage. Temperatures below this limit will give relatively smaller amounts of soluble residue, but will afford results, nevertheless, that are strictly comparable for the clays treated.

After heating at the temperature stated for seventy minutes the mass was removed from the crucible and digested for five hours in hot dilute (1 : 3) hydrochloric acid. The insoluble matter was filtered out and treated with a ten per cent hot solution of Na_2CO_3 until no flocculent silica was observed on testing with ammonium chloride. The insoluble was given a final washing with twenty per cent hydrochloric acid solution, ignited and weighed. The weight of the undissolved residue divided by two (since two grams of clay were taken) gives the percentage of insoluble or the hydraulic factor.

The first trials of this method with Iowa clays are not strictly comparable with the Ohio Survey work since the conditions of burning were modified to some extent. The value of the results, therefore, can be determined by employing as a standard the

	CHEMICAL ANALYSES.											$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	Hydraulic Factor	ANALYST.
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	H_2O+	$H_2O—$	CO_2			
Blue Shale—Mason City	51.95	18.34	7.56	4.14	3.26	3.12		2.76	7.39	.42	3.06	2.01	.2645	J. B, Weems.
Yellow Shale—Mason City	54.56	16.32	14.30	4.10	2.13	2.32		2.30	4.19	.30	5.61	1.78	.2375	L. G. Michael.
Shale—Decorah	17.45	5.57	9.15	30.21	1.95	2.53		1.67	5.57	.25	26.02	1.17	.220	L. G. Michael.
Shale—Flint Brick Co.	63.75	19.87	5.57	1.55	1.22	2.77		2.70	0.67		1.51	2.50	,273	J. B. Weems.
Shale—Fort Dodge	70.20	16.70	4.00	.28	.63	3.14		.83	....	0.53		3.40	.4690	J. B. Weems.
Shale—Lehigh P. C. Co., Mitchell, Ind.	59.64	19.14	7.59	.26	2.81	4.33		....	4.36		.35	2.23	.227	U. S. Geolog. Surv. Bull 243, p. 144.
Shale—Panora, Iowa.	53.82	17.53	5.65	4.40	2.19	1.74	1.12	3.34	....	2.62	....	2.32	.1053	A. O. Anderson.
Shale—Glendon, Iowa	48.91	17.66	6.62	5.42	1.90	2.61	1.44	.28	....	1.60	....	2.01	.1149	A. O. Anderson.
Shale—Farmington, Iowa	35.48	15.85	5.43	12.56	6.24	1.59	.26	3.36	....	1.88	....	1.66	.3298	A. O. Anderson. C. C. Clauson.
Shale—Osceola, Iowa	55.52	14.59	9.09	5.00	2.60	1.50	1.32	.28	......	1.39	....	2.30	.2809	A. O. Anderson.
Shale—Winterset, Iowa	64.74	18.07	6.90	1.25	1.30	1.09	.41	.15	....	1.99	....	2.59	.2578	A. O. Anderson.

figures obtained from tests of clays which are now in use and known to give satisfaction in the manufacture of standard brands of Portland cement. For this purpose a sample of the shale used at the Lehigh Cement Company's Mill C at Mitchell, Indiana, was similarly tested and the factor included in the table appended. It will be noted that the hydraulic factor runs, in those clays which were at all favorable, from .2645 to .22, while the Mitchell shale gave .227.

In a later series of tests made in 1907 somewhat more uniform temperatures were employed, ranging between 1000 and 1060° C. The results of these tests appear as the last five members in the appended table. It will be noted that the minimum value of the hydraulic factor is .1053, in the case of the shale from Panora, Iowa.

CALCULATION OF CEMENT MIXTURES.

Experience has shown that the raw materials for cement must be blended in certain proportions, which range within narrow limits, in order to produce a high grade and uniform product. These proportions depend on the results already obtained by chemical analysis of the clay and limestone or marl to be used and are calculated from the percentage compositions of these ingredients. A lack of agreement among investigators as to the final constitution of the cement clinker has given rise to somewhat varying methods of proportioning the ingredients in the raw mixture. The methods employed are best illustrated by examples. E. C. Eckel* expresses the relation between the argillaceous and calcareous materials by the following ratio which is termed the Cementation Index.

$$\frac{(2.8 \text{ x percentage silica } (SiO_2)) + (1.1 \text{ x percentage alumina } (Al_2O_3)) \text{ x } (.7 \times \text{ percentage iron oxide } (Fe_2O_3)).}{(\text{Percentage lime } (CaO)) + (1.4 \text{ x percentage magnesia } (MgO)).}$$

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* Cements, Limes and Plasters, Wiley & Sons, p. 391.

The proper proportions are present when this ratio is equal to unity. If the value falls below 1.0, free lime or magnesia will be present; if it rises above 1.0, there is a deficiency of lime. Based on the above relations the process of calculation would be as follows:

Analysis of Raw Materials.

SHALE FROM GLENDON, IOWA.		LIMESTONE FROM EARLHAM, IOWA.	
SiO_2	48.91	Insoluble siliceous	7.85
Al_2O_3	17.66	$Al_2O_3 + Fe_2O_3$	1.00
Fe_2O_3	6.62	CaO	51.05
CaO	8.42	MgO	.29
MgO	1.90	CO_2	40.43
$K_2O + Na_2O$	4.05		
Loss on ignition	11.83		

Operation 1. Multiply the percentage of silica in the clayey material by 2.8, the percentage of alumina by 1.1, and the percentage of iron oxide by 0.7; add the products; subtract from the sum thus obtained the percentage of lime oxide in the clayey material plus 1.4 times the percentage of magnesia and call the result *n*.

Operation 2. Multiply the percentage of silica in the calcareous material by 2.8, the percentage of alumina by 1.1, and the percentage of iron oxide by 0.7; add the products and subtract the sum from the percentage of lime oxide plus 1.4 times the percentage of magnesia in the calcareous material; call the result *m*.

Operation 3. Divide *n* by *m*. The quotient will be the number of parts of calcareous material required for one part of clayey material.

The clay:

(Silica) $48.91 \times 2.8 = 136.95$
(Alumina) $17.66 \times 1.1 = 19.37$
(Iron oxide) $6.62 \times 0.7 = 4.63$

160.95

(Lime) 8.42
(Magnesia) $1.90 \times 1.4 = 2.66$

11.08

$160.95 - 11.08 = 149.87 = n.$

The limestone:
(Siliceous matter) $7.85 \times 2.8 = 21.98$
(Alumina + iron oxide) $1.00 \times 1.1 = 1.10$
23.08

(Lime) 51.05
(Magnesia) $.29 \times 1.4 = .41$
51.46

$51.46 - 23.08 = 28.38 = m$. Then,

$\frac{n}{m} = \frac{149.87}{28.38} = 5.28$ parts limestone by weight to be used for each part of clay. In practice, it has been found best to reduce the amount of limestone about ten per cent from that obtained by the formula since the latter stands for the highest quantity of lime that will theoretically combine with the clay.

Bleininger gives the following method of batch calculation.* The Glendon shale and Earlham limestone whose analyses are given above are used.

The formula assumed for the burned product is: $(2.8CaO) SiO_2$. $(2CaO) Al_2O_3$, which requires for each part by weight of silica 4.66 parts of calcium carbonate, and for each part of alumina, two parts of the lime carbonate. Therefore,

(Silica) $48.91 \times 4.66 = 227.92$
(Alumina + iron oxide) $24.28 \times 2.00 = 48.56$
276.48 lime carbonate to satisfy the silica and alumina of the clay.

The clay already contains 8.42 per cent CaO (= 15.03 calcium carbonate) which it will contribute to the mixture and which must therefore be subtracted. At the same time, the limestone contains silica, alumina and iron oxide which must be taken into account. We have therefore,

$276.48 - 15.03 = 261.45$ parts calcium carbonate to be added to the clay; and from limestone analysis, calcium carbonate, 91.15 $(= 51.05 \times 1.785) - (7.85 \times 4.66 + 1.00 \times 2) = 52.57$.

$7.85 \times 4.66 + 1.00 \times 2 = 38.58$ parts of lime carbonate that will combine with the other ingredients of the limestone.

Total lime carbonate in the limestone, $91.15 - 38.58 = 52.57$ parts calcium carbonate available from the stone. 261.45 parts are required. The amount by weight of limestone for one part of clay is 261.45 divided by 52.57 = 4.97.

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* Bulletin 3 (4th series), Ohio Geological Survey, p. 239.

In the above calculations the magnesia is neglected and the ferric oxide is taken with the alumina. Where these constituents are low in amount such procedure is permissible but it has been shown that the influence of iron and magnesia is such that they should have separate consideration. They are thus comprehended in the formula given on page 85, and to this extent the first method of calculation is the more accurate.

The two methods given are applicable for determining the correct proportion in which to blend new and unused raw materials as well as a means of control over mixtures already in use. In the latter instance, however, more rapid means are commonly employed. Experience with given materials will determine the limits within which they may vary and still afford a satisfactory cement. The total amount of the lime and magnesium carbonates is frequently made the basis of control. Their percentages are quickly ascertained by the chemist and the limestone or marl and the clay apportioned accordingly. Bleininger* gives the following formula for calculating the daily mixture after once the best proportion of a mixture has been established, which depends essentially on the calcium oxide in the raw materials:

Let x = weight of limestone in charge
y = weight of clay in charge
a = per cent of calcium oxide in the limestone
b = per cent of calcium oxide in the clay
c = per cent of calcium oxide in the mixture.

$$\text{Then } c = \frac{ax + by}{x + y} \text{ or } x(a - c) = y(c - b) \text{ or } \frac{x}{y} = \frac{c - b}{a - c}.$$

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* Bulletin 3 (4th series), Ohio Geological Survey, p. 242.

PHYSICAL TESTS OF IOWA LIMES

BY

S. W. Beyer

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S. W. BEYER.

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CHAPTER II

GENERAL CONSIDERATIONS.

The lime of commerce is produced by the calcination of limestone and varies in composition and purity as do the limestones themselves. The latter range from practically pure calcium carbonate ($CaCO_3$) to the sandy and clayey limestones in which the impurities compose a large percentage of the rock. Again, the calcium may be in part replaced by magnesium which gives the magnesian limestones. If this replacement has taken place to the extent that magnesia (MgO) comprises 18 to 20 per cent of the stone, the term dolomitic limestone is more commonly applied.

A limestone composed essentially of $CaCO_3$ will furnish a high grade of quicklime, one containing little else than CaO; one composed of $CaCO_3$ with a greater or less percentage of $MgCO_3$ will afford a magnesian or dolomitic lime; while the argillaceous limestones will give a product of a degree of purity depending on the amount of clay in the original stone. The properties of the resulting limes will vary according to their composition.

Limestones are widely distributed in nature, both geographically and geologically. They are found interbedded with and overlapping other common sedimentary strata, and they have been produced in much the same way as other sediments. Good reasons are readily conceived why they should be apt to partake of the nature of, and to grade into or be contaminated with, other sedimentary materials. It is, nevertheless, not at all uncommon to find limestones that run over 90 per cent lime carbonate, and occasionally as high as 98 or 99 per cent. The analyses of nine samples of non-dolomitic Iowa limestones show a range of from 82.5 to 97.02 per cent carbonate of lime, three of the nine samples showing over 90 per cent.

As indicated, limestones depart in composition most commonly in the content of magnesia and in the clay and sand impurities. The effect of these substances on the resulting lime is of so much importance that they may be given separate consideration.

WHITE VERSUS BROWN LIMES.

A pure limestone when burned changes to calcium oxide (CaO) by the loss of carbon dioxide (CO_2) gas. The resulting lime is the white lime of commerce. It slakes readily and rapidly, with the evolution of much heat and becomes a perfectly white paste. The chemical reaction in slaking is:

$$\underset{\text{Quicklime}}{CaO} + \underset{\text{Water}}{H_2O} = \underset{\text{Slaked lime}}{Ca(OH)_2} + \text{heat}$$

This reaction with CaO furnishes with maximum intensity all of the evidences of the chemical change which is taking place. Any impurities in the quicklime, which may have been present in the limestone, tend to retard and to make less vigorous the slaking process, but the quantity of the impurity must be considerable before any pronounced interference will be noticeable.

Dolomitic limestones are very common and produce limes that slake slowly, evolve less heat and are of a gray or brown color. Over ten per cent of MgO must be present to appreciably alter the properties of a lime. Limes containing less than 10 per cent MgO are accordingly spoken of as magnesian limes, while those with over 10 per cent are properly called dolomitic or brown limes. Dolomitic limes produced from Iowa limestones range in magnesia content from 15.23 to 35.73 per cent in the marketed product.

With reference to the amount of magnesia contained, therefore, limes may be classified; (a) hot, white or high-calcium limes when MgO is below 10 per cent; and (b) cool, brown, or dolomitic limes when MgO is over 10 per cent. The value, properties and adaptability of the two classes will be briefly treated later.

WHITE VERSUS ARGILLACEOUS AND SILICEOUS LIMES.

Limestones which contain clayey matter produce limes that are gray in color and less vigorous in their action than the pure white limes. Sand or other siliceous impurities in the lime do not ordinarily exert any influence on its physical properties, acting simply as a diluent in the same way that sand does in a mortar. Should the latter be excessively fine, however, it may become susceptible to chemical combination with the lime if high temperatures are employed in the burning. As the amount of sand and clay increases, limestones are called sandy or arenaceous and argillaceous, and when these materials become the predominant constituents, the rock passes into calcareous or limy sandstones and shales.

The presence of a small proportion of the above named impurities causes limes to become hydraulic, that is, to possess the property of hardening under water, by the gradual taking of water into chemical combination. When the quantity of clayey impurities in the limestone reaches 6 per cent, they begin to produce hydraulicity. Below 6 per cent the only noticeable effect is in the retardation of slaking. Limestones carrying 6 to 12 per cent furnish limes that are cool and slow slaking, gray in color and make the best of mortar if burned at ordinary lime kiln temperatures. There is, however, much greater danger of overburning than in the case of white limes as the clay has a tendency to combine with the lime, which decreases its value unless finely ground. Fifteen to twenty-five per cent of clay renders a lime strongly hydraulic if properly burned, but care is required to avoid overburning and consequent clinkering. If clinkering is permitted to take place, the product is found to possess, after fine grinding, a hydraulicity greater than that of the hydraulic limes and similar to cement, which property becomes more prominent the greater the clay content and the higher the temperature of burning. The limit at present is Portland cement in which the raw materials are artificially blended and thoroughly clinkered at very high temperatures.

It is clear, therefore, that limes are but one end of a series of products of which Portland cement is the other. The dividing lines separating the various members of the series that are put upon the market are to some extent arbitrary. The following four divisions are commonly referred to:

1. Common or fat limes.
2. Hydraulic limes.

3. Hydraulic or Roman cements.
4. Portland cement.

The points of distinction between 1 and 2 have been noted. In composition, 2 and 3 are not separable. By an increased temperature in burning some hydraulic limes will become hydraulic cements. Twenty-four per cent of clay is about the permissible upper limit for the hydraulic limes, while Roman cements are in use which contain but little over 20 per cent of clayey impurities. The chief distinguishing feature of these two groups lies in the ability of the limes to slake to a paste with water without previous pulverization. Fine grinding is necessary before water will affect appreciably Roman cements and before they will harden as a mortar.

The feeble hydraulicity of the limes and the relatively strong of the cements appears to be due to the varying degree to which chemical combination has been brought about in burning. In lime burning, little if any chemical action occurs between the lime and the clay. What does take place tends to produce an unstable or "unlocked" condition of the clay and other siliceous materials such that, in the presence of water, the lime hydrate slowly attacks these and combines with them to form silicates that are harder and more durable than ordinary lime mortar. Clinkering in burning, is an indication of chemical action, further progress in rendering available and susceptible to the attack of the lime and water the clay and other siliceous substances in the stone. Burned to this condition, the product is properly termed a cement and in use attains a stony hardness and relatively great permanency.

Hydraulic or Roman cements are spoken of also as natural or rock cements, since they are made from limestones in which the ingredients occur naturally in the proper proportions. Such limestones are found in different parts of the United States, but have been utilized principally in the Appalachian states of the East and along the Ohio river. The actual composition ranges between wide limits as shown in the table below in which are compiled the analyses of five reputable brands of natural cements:

Analyses of Natural Cements.

NAME	Silica	Alumina	Iron oxide	Lime	Magnesia	Alkalis	Loss on ignition
"Fern leaf" brand, Louisville, Ky.	26.4	6.28	1.00	45.22	9.00	4.24	7.86
N. L. & C. Co., Rosendale, N. Y..	30.5	6.84	2.42	34.38	18.00	3.98	3.78
"Hoffman," Rosendale, N. Y.....	27.3	7.14	1.80	35.98	18.00	6.80	2.98
Utica brand, Utica, Ill............	27.6	10.60	0.80	33.04	7.26	7.42	2.00
Mankato, Minn....................	28.43	6.71	1.94	36.31	23.89	1.80	0.92

Numbers 3 and 4 in the outline on page 98, bear to some extent a similar relation to that briefly given for 2 and 3. A more complete vitrification of the ingredients in the cement mixture until they issue from the kiln as thoroughly vitrified clinker produces the maximum amount of hydraulic silicate. The chemical changes which occur in burning are complicated and become more so the higher the temperature over that employed in the manufacture of natural cement. Just what these changes are is not accurately known, but experimentation has determined within fairly narrow limits what proportions of the various constituents entering into a mixture of clay, silica and limestone will produce the greatest amount of unstable, hydraulic silicate, and what temperatures are required to accomplish this result. These proportions and temperatures are employed in the manufacture of Portland cement and are considered in Chapter I.

The foregoing remarks will serve to show the relation of limes as a mortar material to other substances used for similar purposes. This paper has to do with limes alone and the several physical properties of the latter that are of chief importance will be briefly discussed.

SLAKING.

The property belonging to limes which makes them of industrial value is their ability to slake or crumble to a powder on the addition of water, and to harden when allowed to stand in contact with the atmosphere. The reaction which occurs in slaking has already been given. If a lime is properly burned, all lime carbonate in the original stone has lost its carbon dioxide, and becomes quicklime (CaO). It is the rapid change accompanied by the evolution of heat when water is added that causes lime to slake. Slaking is a physical evidence of the hydration of lime, but it is not to be understood that slaking is a necessary result of such chemical action. The two processes are really distinct. The exposure of caustic lime to a moist atmosphere occasions slow hydration, accompanied by crumbling to a powder. Along with this change occurs an increase in volume of about 1¾ times that of the original lime. Such lime is air-slaked and is largely changed to the hydroxide $Ca(OH)_2$. If this lime be exposed to water, it will further increase in volume, but the paste resulting will be sharp and sandy in texture, and of much less value for mortar purposes than freshly slaked lime. In this case a portion of the CaO has no doubt combined with the CO_2 of the air, so that air-slaked lime is actually a mixture of lime hydrate and carbonate. It is possible also to bring about the complete hydration of lime by steam at temperatures above boiling, without any change of volume or any sign of crumbling.

Slaking may therefore be defined as the hydration of calcium oxide, quick-lime, accompanied by an increase in temperature and volume. The increase in temperature is caused by the combination of the lime and water. It is an exothermic reaction, one in which heat is evolved. Whether or not this heat becomes evident depends on the vigor and rapidity of the reaction.

Slaking is commonly accomplished by the addition of sufficient water to cover the lime, and by further additions as needed. It is desirable from the practical standpoint that the greatest possible increase in volume be secured in slaking. This is accomplished by careful control of the amount of water throughout the process. The evolution of heat in such quantities as to generate steam within the mass is a necessity to the slaking process. At the same time, more water than simply that required for hydration is essential. It is the expansion of the steam between the molecules of hydrating lime which forces them apart and causes the mass to crumble. As the particles are separated, the surrounding excess of water acts to remove them, as in the case if any fine sediment, and, as they settle away in partial suspension, new surfaces of the lime are constantly exposed. A large excess of water prevents proper slaking by keeping the temperature so low that the necessary steam does not form. The mass then expands poorly, slakes slowly, and the product is lumpy. The lime is said to be "drowned".

The result of too little water is a "burnt" lime. In this case, the water forms a gelatinous film of hydroxide over the surface of the lumps which dries down, enclosing caustic quick-lime in the center, and so clogs the pores that further progress is much retarded or prevented. When too little water is used, the initial action is apt also to be so violent in the case of "fat" limes, that much or all of the moisture passes off as a vapor, because of the excessive temperature developed. This frequently leaves the lime but partially hydrated, dry, and imperfectly slaked.

Dolomitic limes slake more slowly and at a much lower temperature than high-calcium limes. The heat generated is due to the hydration of the calcium oxide, the magnesia remaining as the oxide during slaking. Although magnesium carbonate loses CO_2 at a lower temperature in burning than does the carbonate of lime, it hydrates only with difficulty and probably passes directly from oxide to carbonate in the hardening process. It is thus necessary to add the water required very gradually in slaking dolomitic limes in order to avoid "drowning" and to secure the best results.

The proper amount of water to use varies, and can be ascertained for each individual lime only by actual trial. It is usually found more satisfactory to add the water in several different portions as slaking progresses, especially with the lean, slow slaking and dolomitic limes. In this way, by a little attention, the temperature of the slake can be controlled so that the best product is obtained from the lime in use.

The expansion of volume in slaking may be as high as 3½ times with pure white limes. It is found to range from 2½ to the figure named. Lean, so called hydraulic limes, and dolomitic limes expand less. Increase in volume is ordinarily estimated by a comparison of the bulk of the dry quick-lime and of the paste after slaking. Careful experiments with samples of both high-calcium and dolomitic limes made by the Ohio Geological Survey* show an increase in apparent volume for the white limes of from 136 per cent, using 20 per cent less water than theoretically necessary for hydration, up to 264 per cent with 40 per cent excess of water. With 300 per cent excess, the increase was but 45 per cent. The comparison was made between the apparent volumes of the ground quick-lime and of the dry hydrate produced. Under the same conditions, a dolomitic lime gave 193 per cent expansion with a deficiency of 20 per cent of water, of 210 per cent with the exact theoretical quantity of water, and of but about 20 per cent with an excess of water. The increase in volume is decidedly in favor of the white lime, the smaller expansion of the dolomitic lime being accounted for, no doubt, by the fact that the magnesia takes up very little water in the slaking process.

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*S. V. Peppel, Bulletin 4, Ohio Geol. Survey (4th series), p. 337.

The *actual* increase is, as a matter of fact, more apparent than real. The calcium hydroxide produced from a weighed amount and accurately determined volume of calcium oxide will occupy a space but 35 to 40 per cent greater than the volume of the oxide. Few experiments have been made along this line and the above figures were obtained with a high grade white lime by the use of the Seger volumeter.

If allowed to stand in the air lime deteriorates by the process of air-slaking already described. It also slowly absorbs carbon dioxide, which renders it of little value for mortar. After slaking, if the paste is not to be used at once, it should be protected from the atmosphere, since moist lime hydrate changes very readily to the carbonate by the absorption of CO_2. Slaked lime is very commonly buried so as to be covered with several inches of soil, where it will keep for months without deterioration.

Owing to the susceptibility to deterioration of the high-calcium limes on the one hand, and the exceeding slowness with which dolomitic limes slake on the other, so-called "hydrated limes" are being put upon the market. The quick-lime is subjected to a partial hydration or slaking at once after burning and before being sacked or barrelled. The completeness of the hydration in the case of five Ohio* products ranged from 58 to 94 per cent, 100 being taken as the best that is possible on a commercial scale. Specially designed and patented apparatus and processes are being employed in the hydration of limes, but it is believed that such special equipment is not necessary, nor will the preparation of hydrated lime without doing so under a patent, make any person liable for infringement. So far as known, no hydrated lime is placed on the market from Iowa kilns.

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* S. V. Peppel, Bulletin 4, Ohio Geol. Survey, pp. 335 and 336.

The desirable qualities of hydrated lime are: (1) its convenience in use, for it is already pulverized and but little time is required to make a mortar by mixing the ingredients dry before adding the water; (2) its lasting qualities, as it will keep much longer without detriment than the unslaked product. Magnesian limes are more commonly prepared in this way, and the saving of time in their use is a very important commercial consideration. Hydrated magnesian limes are found by the Ohio Survey* to have specific gravities of 2.12 to 2.25. High-calcium limes run about 2.45. A series of tests with an Iowa white lime gives specific gravities from 2.2 to 2.32 for the slaked lime, while the quick lime is 2.08.

SETTING AND HARDENING.

In slaking, the lime takes water into chemical combination, and becomes the gelatinous hydroxide. When this hydroxide is put in place as a mortar, it is said to set. This preliminary set is due to the loss of the water used in mixing, which brings about a certain rigidity in the same way, so far as is known, that clay becomes hard on drying. Part of the moisture evaporates from exposed surfaces, but the larger proportion is in most instances absorbed by the porous brick or other masonry material with which it is used. The more rapid the set, that is, the more rapidly the mortar loses its water, the safer the construction, providing the proportions of sand and lime are such that shrinkage may be left out of account.

A second process begins at once when the lime is exposed to the air. This is the absorption by chemical combination of carbon dioxide by which the lime returns to the carbonate condition, as it existed in the original limestone. The process is a slow one and may require years for completion, but this depends largely on the surface that is exposed, the thickness of the layer and porosity of the mortar. A large number of chemical tests on small briquettes having a minimum cross section of one square inch, made with mixtures of sand as high as 6 to 1, and allowed to stand for a maximum period of one year, showed none in which carbonation was complete. This action is most rapid in the first few months until a crust of the carbonate forms on the exterior. The crust retards the process and at the same time protects the soluble hydrate within from being dissolved. The interior portions of large masses may, therefore, never reach this final condition in hardening.

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*S. V. Peppel, loc. cit.

Long contact of lime hydrate with finely divided silica is known to cause a reaction by which the silica combines with the lime forming a stable silicate of lime. The extent to which this reaction progresses depends on the physical and chemical qualities of the siliceous impurities in the lime or of the sand used with it. If these are very fine, chemical action is favored. Silicates, such as clay or feldspar, for example, are more susceptible to attack by the lime than is quartz sand. Hydraulic limes are apt, therefore, other things being equal, to give a more durable final product than the purer limes. In the same way, muddy or clayey sand used with lime, although less desirable at the start, will likely contribute to the durability of the mixture in time because of the development of these stable compounds by the caustic action of the lime. In the case of silicates, it is probable that other elements, especially alumina, also enter into combination.

Lime Mortar.

Sand.—Lime has a variety of uses in various industries but by far its most important application is and has been as a mortar in structural work, interior wall plastering, etc. For these purposes, slaked lime alone can not be used on account of the great shrinkage of the lime paste in setting and its lack of inherent strength when set. It is, at the same time, economical to add some foreign material which is cheaper than the lime itself. The filling material commonly employed is sand. Most sands are composed largely of quartz grains, although fragments of feldspar and of many other minerals are often found in varying amounts with quartz. There is often also more or less of earthy or clayey matter in sands.

In general, it may be said that the composition of the sand is not an important consideration. Any inert substance which does not shrink nor deteriorate may be used. Ground limestone, for example, or the pulverized sand from any durable rock will serve the purpose equally well.

The physical condition of the sand is, however, of considerable importance. The function of the lime is to serve as a binder to hold the particles of the aggregate together. If these particles are angular and rough, they afford good surfaces for the attachment of the lime. Sharp sand will therefore make a stronger mortar than one composed of rounded grains. Only sufficient lime is required to fill the voids and to form a thin film around each grain of the aggregate. The more nearly the voids are filled with the sand grains themselves, in other words, the smaller the percentage of pore space in the sand, the less the amount of lime needed. A sand composed of a properly proportioned range of sizes of grain will therefore not only give the strongest product but will do so with the least amount of lime. Few sands as they occur naturally are composed of the proper range of sizes to give the smallest pore space. It is sometimes not difficult, and often may be a matter of economy, to correct a poorly proportioned sand by screening or by the addition of suitably graded materials. The voids in a sand are determined readily with simple apparatus.* Separation into a series of sizes is quickly done by sieves of a number of different meshes. These two tests afford data as to how far a given sand departs from the ideal mixture of grains and indicate the size of grain and quantity to be added for correction.

The sand grains should be practically in contact throughout the mass so that the lime paste forms merely a plastic film filling the interstices. Such a mortar when it has attained its final hardness may properly be regarded as sandstone in which the cementing matter is lime carbonate. It differs from the natural stone only in its position and origin, being as strong, if properly made, and as durable as that quarried from natural ledges.

White limes shrink much more in drying than do dolomitic limes. For this reason is it more highly important that the proper proportion of sand be used with the former. The bonding or adhesive power of white limes is also less. This is evidenced in walls where the mortar separates readily from the brick and can itself often be crumbled in the fingers. Such defects are believed to be due more to poor mixing and wrong proportions of sand and lime than to any inherent quality of the lime itself. On the other hand, dolomitic limes possess great adhesive strength and not only form a denser mortar by binding the sand particles firmly together, but contribute towards the stability of the wall by adhering to the brick or stone.

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*Standard sand for Cement work, M. J. Reinhart, Proc. 3d Ann. Convention Iowa Association Cement Users, Ia. Eng., Vol. VII, No. 1, p. 34.

TESTS OF LIME MORTARS.

Although lime has been used as a mortar since very early times and is of late being employed in various other ways in structural engineering work, few records of tests of those physical properties which make it of value are to be found. The purpose of the following series of tests is to investigate several of the physical properties of lime mortars, covering the following points:

(a) The influence of slaking with increasing amounts of water;

(b) The increase in strength with increased setting periods, and, since in practice, limes are seldom used in a neat condition;

(c) The effect of varying proportions of sand on the strength of the mortar, and the rapidity of setting. There has also of late been considerable discussion as to the relative merits of the white or high-calcium limes, and the brown or magnesian limes.

To obtain definite data on these several points, the following plan was adopted in the beginning. Barrel samples of commercial limes were obtained from the principal producers in Iowa, and a few from bordering states. Samples of white lime were tested from Springfield, Mo., and Mason City, Iowa; of dolomitic lime from Viola, Iowa; Mason City, Iowa; Maquoketa, Iowa; and Eagle Point, Iowa.

While it was evident that the factors enumerated above were the important ones to be studied, with each lime it was necessary to carry on considerable preliminary experimenting in order to be able to lay out an exact systematic method of procedure. A provisional line of experiments was therefore initiated, using the white lime from Mason City. The quick-lime was slaked with percentages of water ranging from the amount which would produce a dry powder as a minimum, to a maximum of 300 per cent by weight. Slakings were then made with 100, 150, 200, 250, and 300 per cent of water, calculated on the basis of dry quick-lime as 100 per cent. From each slaking, series of briquettes were made with the following sand dilutions,* by weight:

One part sand to 1 of lime, 1½ of sand to 1 of lime, 2 of sand to 1 of lime, and so on to 5 parts of sand to 1 of lime. Four sets of briquettes were made from each sand mixture to be broken at the end of four, eight, twelve, and sixteen weeks respectively. Ten briquettes were used in each set from which to obtain an average.

Briefly, then, from the lime paste obtained by slaking in each of *six* different percentages of water, briquettes were made with *nine* different dilutions of sand. Since four periods of set were to be allowed, with ten briquettes to be broken at the expiration of each period, a little arithmetical calculation will show that for each lime tested, according to this plan, 2160 briquettes would be made. As the work progressed, it was soon discovered, however, that this general scheme required more or less modification according to the peculiarities of each particular lime.

HIGH-CALCIUM WHITE LIMES.

LIME FROM MASON CITY, IOWA.

The limestone from which the Mason City lime is produced comes from the Devonian beds, and has the following analysis:

Water	0.51
Insoluble	.63
Alumina and iron oxide	.71
Lime (CaO)	54.59
Carbon dioxide	42.89
Magnesia (MgO)	.47
Carbon dioxide	.52
	100.32

Analysis of the commercial product:

	Quick-lime.	After slaking.
Insoluble	1.02	0.60
Alumina and iron oxide	2.98	2.80
Lime (CaO)	95.40	71.10
Magnesia (MgO)	.43	.40
Loss on ignition	0.00	25.60
	99.83	100.50

A sufficient quantity of quick-lime was slaked at one time to make the full number (360) of briquettes as planned for each percentage of water. Precaution was taken in slaking to add the water in such quantities and to agitate the mass so as to facilitate the process and to obtain the greatest increase in volume with the amount of water employed. The lime paste was allowed to stand for twenty-four hours until all signs of heat had disappeared and then put into air-tight jars to be used as needed. All weights were calculated on a dry basis, the moisture being determined before each batch of both sand and lime was weighed out. In the case of the higher percentages of water, it was necessary to drive off by careful heating, care being taken to keep the temperature below boiling, some of the excess water, in order to reduce the paste to a workable consistency. One man did the work, using his judgment to obtain as nearly as possible the same consistency in every batch. Forty briquettes were made from each mixing. The briquettes remained in the molds until they could be safely removed, after which they were placed on edge on open shelves and allowed to harden for their respective periods.

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* A standard river sand was used throughout the tests, whose grains passed a 20-mesh (linear) sieve and remained on a 30-mesh sieve.

The tensile strength test was adopted as a means of obtaining comparable results more because of its convenience and the uniform treatment to which each lime would be subjected, than as representing conditions which lime mortars would meet in actual use. As noted earlier, the principal function of a mortar is to serve as a matrix or adhesive to bind together particles of aggregates and sections of masonry structure. Adhesion, therefore, and crushing strength tests would give more direct results. Such tests have not as yet been made.

Records of tensile strength tests of lime mortars are to be found in the Report of the Secretary of War for 1896, Document No. 2, Volume II, part 5, on page 2839. These tests were made with paste slaked with 300 per cent of water, ratios of sand from 3.1 to 17.7 : 1, and setting periods of twenty-eight and twenty-nine days and three months. Average strengths range in the short time tests from sixty-four pounds with a ratio of 8.8 : 1 to twenty pounds per square inch with a sand-lime ratio of 17.7 : 1 and, in the three months tests from seventy-one pounds with a ratio of 8.8 : 1 to thirty-six pounds with a ratio of 17.7 : 1. Tensile strength has also been investigated by the Ohio Geological Survey.* The following table will indicate the results obtained:

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*S. V. Peppel, Bulletin 4, p. 337.

Physical Tests of Ohio Limes.

Kind of Lime	Tensile strength of mortar after 7 days. Mortar made by adding 4 volumes of sand to 1 volume of quick-lime	Remarks
High-calcium or white lime	48.95	Water 20% less than theory for complete hydration.
	70.6	Theoretical amount of water.
	59.	100% excess. Product, moist powder.
	42.36	Broke badly. Defective briquette. 100% excess. Heat applied in slaking.
	48.95	200% excess. Moist, lumpy mass.
	65.90	Briquette cracked before going into machine. 300% excess. Smooth stiff putty.
Dolomitic or brown lime.....	24.48	Bad briquette. 20% less water than theory for complete hydration.
	77.2	Theoretical amount of water.
	58.	Bad briquette. 20% excess.
	81.90	40% excess.
	82.84	Sticky, lumpy, mass. 100% excess.
	68.	Bad briquette. Stiff putty. 200% excess.

The period of set allowed in these tests is entirely too short for valuable results. But one briquette seems to have been made for each percentage of water. It is evident that a much larger number should be used to obtain an average figure.

A similar line of experiments made by Mr. George S. Mills, of Toledo, Ohio,* affords results which bring out quite clearly the relative strength of the white and brown limes and the relation of strength to progress in setting and hardening of the mortar. The mortar was made with two parts sand to one of slaked lime by weight. The strength is expressed in pounds per square inch. From four to six breaking strengths were used for each period to obtain the average results given in the table:

	1 month	2 months	3 months	4 months	6 months	1 year
Dolomite lime..........	....	28.8	37.2	51.	83.	92.8
High-calcium lime......	30.7	36.6	39.2	39.	50.8	44.6

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*Municipal engineering, Vol. 28, p. 6.

The Mason City lime is a hot lime, which slakes vigorously and requires constant attention when water is given to it. The quantity of water which would just leave the hydrate practically a dry white powder when it had cooled to the atmospheric temperature was found to be about 75 per cent of the weight of the dry hydrate.

The table below gives in detail the breaking strength of the briquettes made with Mason City lime. A Fairbanks Standard Testing Machine was used.

TABLE I.

Time of set in weeks	Ratio sand to lime	Lbs. Per Square Inch			Ratio sand to lime	Lbs. Per Square Inch			Ratio sand to lime	Lbs. Per Square Inch		
		Average	Maximum	Minimum		Average	Maximum	Minimum		Average	Maximum	Minimum
SLAKED IN 75 PER CENT OF WATER.												
4	1 :1	48.4	51.4	38.5	1½:1	45.7	50.5	39.5	2 :1	54.5	64.4	46.1
8	....	50.6	56.3	47.5	....	40.7	44.5	35.0	....	54.3	63.3	45.0
12	....	56.1	60.4	45.0	....	47.1	50.0	44.3	....	48.5	52.5	46.0
16	....	53.9	50.0	42.0	....	46.2	49.4	40.8	....	53.0	55.9	41.2
4	2½:1	55.1	60.4	50.4	3 :1	50.6	56.2	41.9	3½:1	48.7	55.0	30.0
8	....	54.6	58.6	51.0	....	52.6	58.4	44.5	....	52.1	56.0	46.5
12	....	46.7	48.5	43.5	....	48.1	51.0	45.9	....	48.0	54.3	42.7
16	....	52.3	56.9	49.5	....	43.4	48.6	33.6	....	32.9	53.0	21.5
4	4 :1	47.2	51.4	43.5	4½:1	43.7	53.0	35.0	5 :1	43.6	58.4	38.0
8	....	47.8	57.0	37 0	....	41.8	52.5	37.0	....	45.9	50.0	34.3
12	....	43.6	49.5	33.7	....	42.6	46.6	38.4	....	42.5	51.4	28.6
16	....	41.5	49.0	28.8	....	44.6	50.0	33.0	....	53.1	55.7	50.0
4	5½:1	37.1	44.1	28.8	6 :1	36.0	39.6	34.6	....	....	....	....
8	....	37.8	45.0	32.6	....	35.9	39.0	31.0	....	....	....	....
12	....	38.5	44.1	33.3	....	33.1	39.4	29.8	....	....	....	....
16	....	38.6	40.8	34.9	....	35.4	41.6	30.0	....	....	....	....
SLAKED IN 100 PER CENT OF WATER.												
4	1 :1	47.3	56.2	39.7	1½:1	57.1	61.9	53.0	2 :1	55.9	73.6	45.4
8	....	56.4	64.8	48.9	....	60.5	68.7	48.5	....	72.3	94.7	55.1
12	....	64.9	76.7	52.5	....	64.4	85.8	45.4	....	76.2	89.8	54.1
16	....	62.9	73.3	53.6	....	73.2	91.6	55.6	....	67.9	83.6	53.1
4	2½.1	54:9	62.5	43.8	3 :1	49.9	65.6	40.9	3½:1	51.0	61.3	44.5
8	....	64.6	80.4	53.5	....	57.0	67.6	51.5	....	54.0	62.8	49.4
12	....	55.0	67.7	41.0	....	54.6	63.6	45.0	....	55.5	68.7	50.0
16	....	57.6	74.4	36.7	....	53.1	58.1	40.6	....	56.8	65.7	51.5
4	4 :1	52.8	59.7	41.2	4½:1	47.6	55.4	38.8	5 :1	64.1	75.4	52.5
8	....	53.8	57.0	50.0	....	49.6	53.0	44.5	....	68.1	74.5	65.0
12	....	52.2	58.7	45.4	....	54.4	58.0	48.5	....	63.7	69.3	57.0
16	....	49.6	58.6	43.0	....	48.7	52.0	43.0	....	65.8	72.5	59.0
4	5½:1	56.4	64.7	52.0	6 :1	53.7	59.2	49.5	....	....	....	....
8	....	56.7	62.0	51.5	....	52.5	54.5	50.5	....	....	....	....
12	....	60.4	73.0	53.4	....	54.7	60.0	49.0	....	....	....	....
16	....	50.4	59.4	41.0	....	47.8	55.0	31.3	....	....	....	....

TABLE I—CONTINUED.

Time of set in Weeks	Ratio sand to lime	Lbs. Per Square Inch			Ratio sand to lime	Lbs. Per Square Inch			Ratio sand to lime	Lbs. Per Square Inch		
		Average	Maximum	Minimum		Average	Maximum	Minimum		Average	Maximum	Minimum
SLAKED IN 150 PER CENT OF WATER.												
4	1 :1	41.0	48.3	33.8	1½:1	47.1	49.9	36.1	2 :1	45.0	53.2	38.0
8	....	40.9	48.9	37.0	....	47.6	64.6	36.1	....	46.9	56.7	40.4
12	....	45.8	55.3	34.0	....	50.8	59.8	40.4	....	52.1	68.3	39.0
16	....	47.6	55.7	39.2	....	57.5	74.5	40.8	....	62.0	81.6	51.5
4	2½:1	55:4	68.7	38.8	3 .1	60:7	68.7	45.7	3½:1	71.9	81.0	61.8
8	....	59.8	78.1	44.4	....	54.0	64.5	47.5	....	60.7	71.4	41.4
12	....	56.6	76.3	42.8	....	63.7	72.1	51.0	....	76.2	84.1	69.7
16	....	55.4	79.9	51.0	....	77.3	83.0	66.3	....	76.3	83.4	64.3
4	4 :1	60.5	67.7	58.5	4½:1	51.7	59.4	44.9	5 :1	46.0	51.5	40.4
8	....	63.9	74.5	59.4	....	58.9	62.6	53.1	....	47.5	51.0	45.0
12	....	69.9	76.8	60.6	....	61.1	64.3	49.2	....	49.6	48.2	42.0
16	....	59.5	70.7	49.5	....	60.5	68.4	58.1	....	60.2	75.5	42.3
SLAKED IN 200 PER CENT OF WATER.												
4	1 :1	45.0	60.6	37.2	1½:1	44.4	58.3	35.7	2 :1	45.2	54.6	38.5
8	....	45.5	62.8	44.3	....	51.0	65.6	43.9	....	57.3	69.7	45.9
12	....	45.2	61.8	42.6	....	40.0	57.1	34.7	....	50.6	61.2	40.0
16	....	47.4	53.1	41.2	....	48.5	67.0	36.4	....	53.4	62.8	46.5
4	2½:1	41.7	55.2	33.4	3 :1	46.9	57.1	37.0	3½:1	46.2	53.1	38.0
8	....	51.2	69.8	38.8	....	55.0	72.4	43.9	....	56.0	67.0	46.5
12	....	50.9	61.8	37.4	....	49.6	65.9	42.3	....	55.2	59.2	52.0
16	....	60.6	68.0	53.1	....	54.0	58.2	48.4	....	57.8	60.8	52.1
4	4 :1	40.6	44.9	38.0	4½:1	41.0	44.1	38.6	5 :1	43.8	46.0	39.8
8	....	47.7	57.3	38.8	....	53.2	63.1	38.8	....	46.3	50.5	42.6
12	....	52.9	60.0	47.5	....	52.2	57.4	45.5	....	53.5	59.6	38.0
16	....	53.0	57.0	45.5	....	54.9	57.1	53.0	....	52.7	54.5	47.0
SLAKED IN 250 PER CENT OF WATER.												
4	1 :1	35.4	37.6	33.2	1½:1	38.9	40:9	33:0	2 :1	37.9	41.0	33.0
8	....	43.2	49.0	36.0	....	45.4	53.2	35.4	....	48.6	56.1	44.1
12	....	38.0	43.9	35.0	....	41.2	46.4	36.8	....	47.4	55.5	42.8
16	....	40.0	45.2	36.0	....	43.9	50.0	36.5	....	51.8	58.9	42.0
4	2½:1	42.7	62.5	38.8	3 :1	52.6	61.0	42.9	3½:1	52.7	60.0	43.4
8	....	50.1	60.2	36.5	....	54.8	63.6	41.0	....	48.5	55.1	40.4
12	....	51.9	63.9	40.4	....	56.8	70.6	45.2	....	56.3	63.3	46.0
16	....	58.9	70.8	46.4	....	58.7	69.0	50.0	....	58.0	62.0	57.0
4	4 :1	43:2	64.0	35.0	4½.1	47.5	58.3	37.4	5 :1	50.2	55.4	30.5
8	....	43.4	48.0	35.0	....	50.9	58.0	35.9	....	56.6	62.2	42.4
12	....	53.0	56.6	49.0	....	54.5	60.0	45.5	....	56.9	61.6	53.0
16	....	51.2	54.0	42.0	....	....	....	....	....	....	....	....

TABLE I—CONTINUED.

Time of set in weeks	Ratio sand to lime	Lbs. Per Square Inch			Ratio sand to lime	Lbs. Per Square Inch			Ratio sand to lime	Lbs. Per Square Inch		
		Average	Maximum	Minimum		Average	Maximum	Minimum		Average	Maximum	Minimum
SLAKED IN 300 PER CENT OF WATER.												
4	1 :1	38.1	47.4	25.5	1½:1	35:6	48:4	26.0	2 :1	36.0	48.4	28.6
8	....	35.8	54.2	27.3	....	35.2	53.6	28.8	....	35.9	43.9	28.6
12	....	43.0	58.3	28.2	....	38.5	54.6	27.8	....	40.7	53.5	34.0
16	....	41.7	57.8	26.6	....	40.8	51.0	34.3	....	41.2	52.1	32.0
4	2½:1	41.8	50.0	35.3	3 :1	40.0	50.5	32.6	3½:1	42.4	50.0	33.3
8	....	46.2	51.0	40.8	....	40.2	53.0	30.6	....	52.1	58.1	45.2
12	....	51.1	60.2	39.6	....	46.1	51.0	36.0	....	52.5	55.0	45.9
16	....	56.8	63.8	50.0	....	47.8	54.0	40.0	....	46.7	58.0	35.0
4	4 :1	38.2	46.5	31.3	4½:1	39.7	43.5	32.8	5 :1	40.7	47.5	35.0
8	....	39.2	51.5	31 9	....	45.8	55.5	38.2	....	48.3	54.9	42.7
12	....	37.6	43.5	28.8	....	43.6	48.5	35.9	....	46.3	52.0	43.0
16	....	43.0	50.5	40.0	....	41.4	49.0	30.7	....	46.1	53.0	30.9
4	5½:1	37.8	44.5	34.0	6 :1	41.7	46.0	36.6	....	....	....	....
8	....	46.7	52.9	38.6	....	46.5	51.3	41.5	....	....	....	....
12	....	46.5	52.4	38.5	....	47.7	54.3	43.1	....	....	....	....
16	....	46.5	58.0	43.2	....	49.8	55.0	44.3	....	....	....	....

From these figures, three sets of curves can be constructed which will bring out in a graphic way the general trend of the results. One set, with sand-lime ratio and average tensile strength as co-ordinates; a second set using the setting periods and tensile strength; and a third, based on the percentage of water used in slaking and the tensile strengths.

Inspection of the table and of the accompanying curves will show that, in general, the strength increases with increase of sand up to 2:1, 2.5:1, and possibly 3:1 in some cases, and that beyond these ratios it decreases. Considered with reference to the effect of different periods of set on the strength, little more is to be observed than an increase in all instances during the first two months. With the longer periods the change is not sufficiently pronounced to afford a characteristic curve.

It is evident that the lengths of time allowed for the lime to set were too short for the maximum strength to be attained. This conclusion is supported by chemical determinations of the carbon dioxide absorbed which show that carbonation is in no instance even approaching completion at the expiration of sixteen weeks. Sufficient time should be allowed for the longest period for all the lime to return to the carbonate condition. Then the

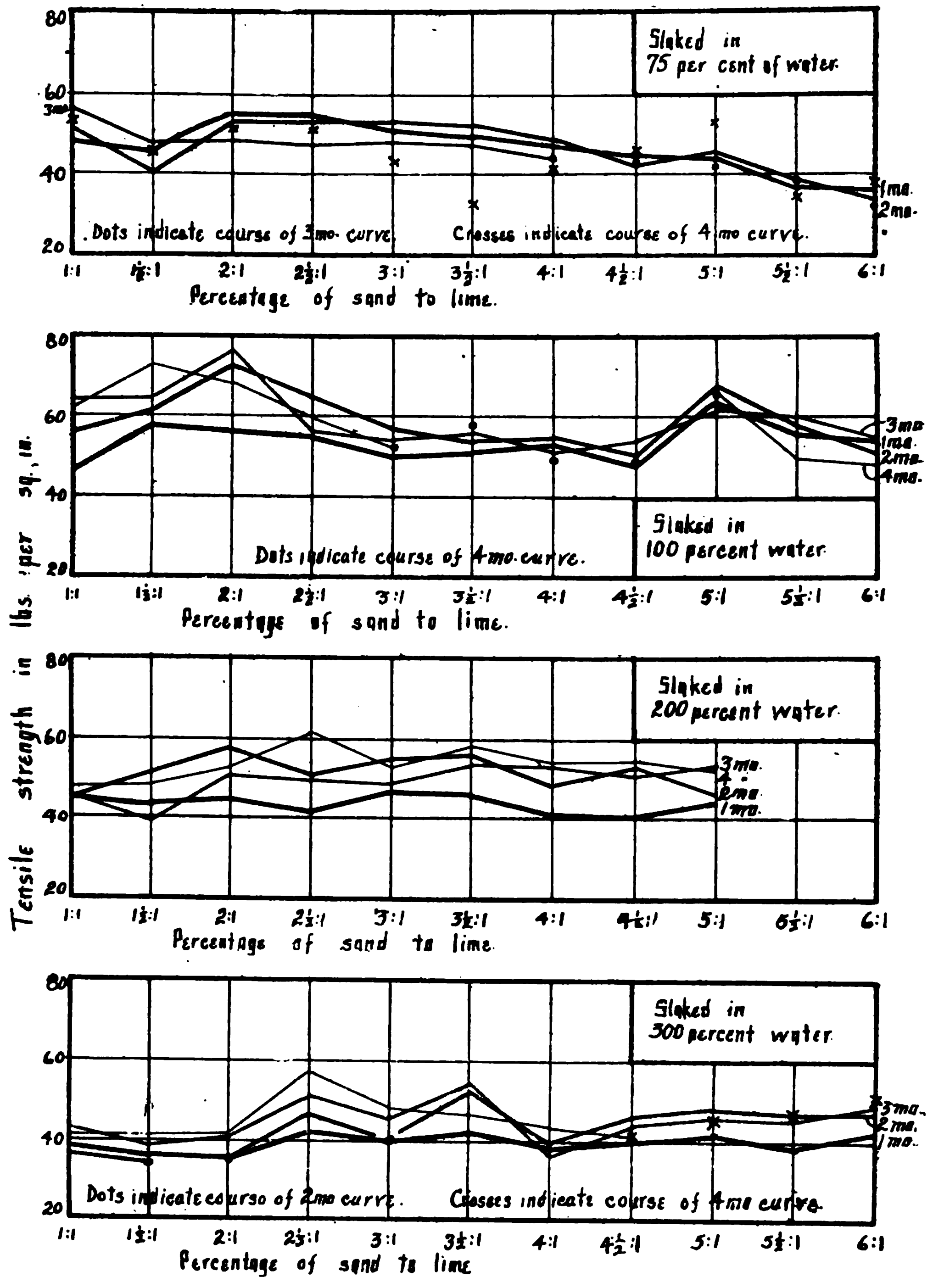

PLATE VI.—Diagrams showing effects of different sand-lime ratios

curves constructed according to the first two methods mentioned above would indicate clearly the progress of the gain in strength according to percentage of sand and setting period.

Plate number VII shows the relation between the percentage of water used in slaking and the tensile strength of the briquettes. They are arranged in groups of four curves, each according to the whole-numbered sand-lime ratios. The general aspect of the five groups taken in conjunction with the tables, indicates a rapid rise in strength at 100 to 150 per cent of water, and as rapid a fall at 200 which continues through the higher percentages. It is to be noted that 100 per cent of water gives the highest strength with the 1:1, 2:1 and 5:1 sand dilutions, while with the two middle members of the series, 3:1 and 4:1, the highest strength is reached with 150 per cent. This may be but a coincidence, with results for only one lime at hand. The percentage theoretically necessary to hydrate the calcium oxide in the lime is but about 30 per cent of the weight of the dry quick-lime. The increase in strength with successively longer periods of time can also be traced from these curves. It will be further noted that the rapidity of increase is greater the higher the percentage of sand used.

The experience gained and the results accruing from the foregoing tests of the Mason City white lime suggested certain changes in the general plan of the experiments. In all the tests whose results follow, the longest setting period is made one year, and sets of briquettes were broken at the end of three, six, nine and twelve months. The percentages of water used for slaking are the even hundreds up to 300 per cent as a maximum, with the exception of the white lime from Springfield, Missouri, in which case 400 per cent of water was used, since it slaked to a dry powder with 100 per cent. The lowest percentage is in all instances the largest possible amount that would leave the slaked product a dry powder. Only the whole-numbered sand-lime ratios are used in the later tests.

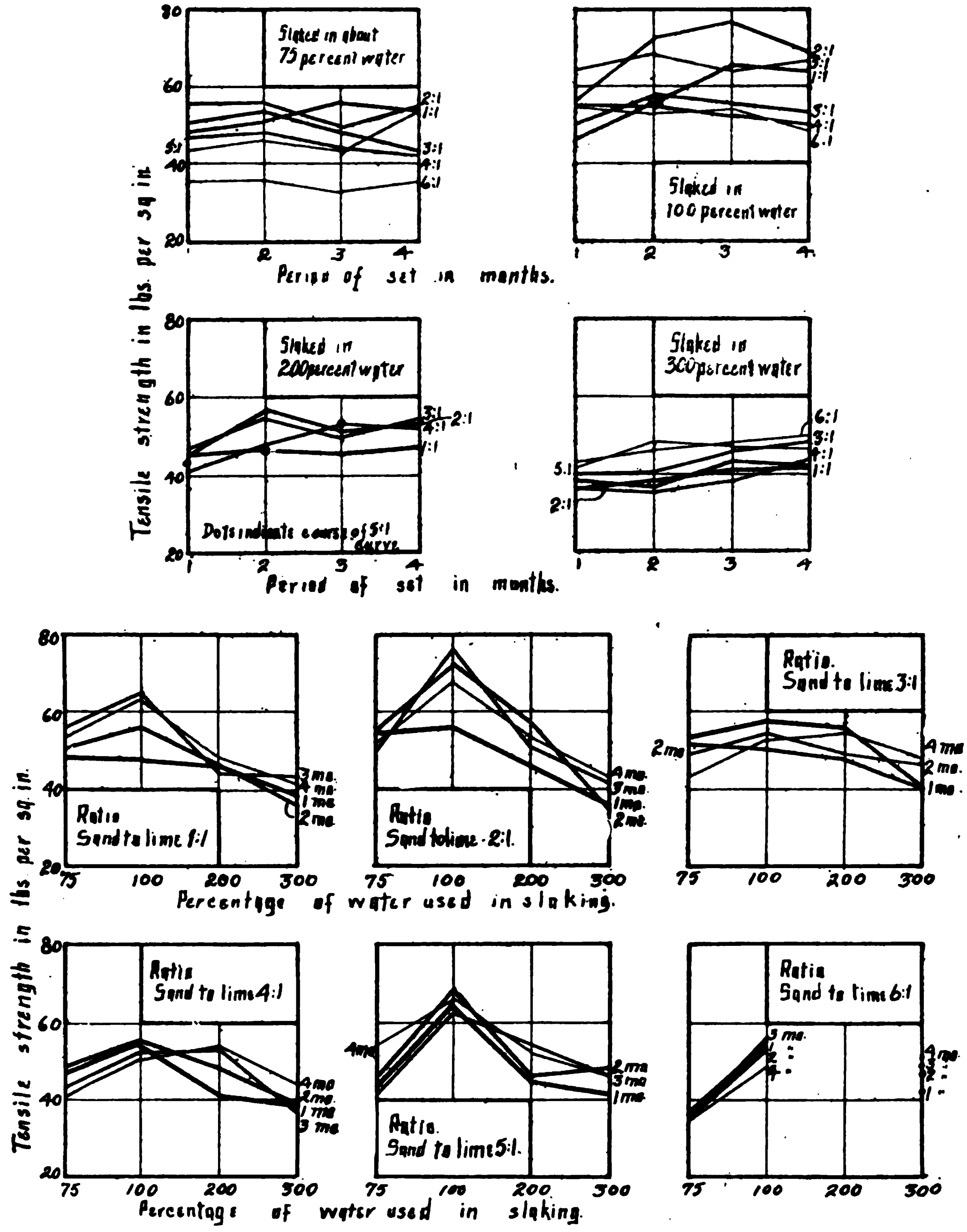

PLATE VII.—Diagrams showing effects of different setting periods and of different percentages of water.

White Lime from Springfield, Missouri.

The limestone from which the Springfield lime is made has the following chemical analysis:*

Lime carbonate ($CaCO_3$)	99.46
Iron oxide (Fe_2O_3)	.21
Silica (SiO_2)	.33
	100.00

Analysis of the commercial product:

	Quick-lime	After slaking
Insoluble	1.00	0.67
Iron and alumina ($Fe_2O_3+Al_2O_3$)	1.80	1.11
Lime (CaO)	94.70	73.20
Magnesia (MgO)	0.40	0.43
Loss by ignition	2.08	24.25
Carbon dioxide (CO_2)	Trace	......
	99.98	99.76

The Springfield lime is unusually pure and, as may be expected, slakes rapidly and with much heat. With 200 per cent of water, it was found difficult to prevent the lime from "burning". Up to 300 per cent of water, it was impossible to keep the paste thoroughly mixed on account of the generation of steam and the violence of the slaking action. 350 to 400 per cent works best and gives a uniform, well slaked product.

It is unfortunate in any investigation if the person beginning the work can not carry it to completion. Even though the training of the experimenters be identical, personal equation always enters, and sometimes to a sufficient extent in small matters of manipulation, and in the exercise of judgment, to produce unexplainable irregularities in results. In the present experiments it was necessary to place the work in new hands at times during their progress. Lack of uniformity in the data which follow can in some instances be accounted for only by such changes, and yet it is not possible to assign absolutely to this cause variations that appear. Notwithstanding all minor deviations from the rule, however, there are revealed certain general truths that are brought out in the results given.

In Table II are compiled the results of the tests of the Springfield lime and these are graphically shown in plates VIII, IX and X, which follow:

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*20th Annual Rep. U. S. Geological Survey, Part VI (Continued), p. 415, also Bulletin 44, N. Y. State Museum, p. 924.

TABLE II.

SPRINGFIELD, MO., WHITE LIME.

Time of set in month	Tensile Strength in Pounds Per Square Inch																	
	Sand to Lime 1:1			Sand to Lime 2:1			Sand to Lime 3:1			Sand to Lime 4:1			Sand to Lime 5:1			Sand to Lime 6:1		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
SLAKED IN 100 PER CENT OF WATER																		
3	96.20	112.0	67.0	93.95	107.7	81.7	68.24	77.6	49.5	56.71	60.0	50.0	61.40	65.0	58.8	48.21	55.0	40.00
6	113.70	121.0	102.0	88.23	105.5	72.1	75.40	96.1	61.5	75.60	82.1	69.2	63.06	68.9	53.4	46.56	50.5	41.60
9	109.40	130.0	97.0	97.03	120.0	79.9	72.74	86.7	61.3	65.70	87.5	45.2	60.70	74.0	50.0	42.81	48.1	38.40
12	114.18	137.0	95.0	95.58	104.0	86.1	70.45	82.5	61.2	62.75	75.5	53.9	51.07	67.6	46.1	40.36	48.5	34.65
SLAKED IN 200 PER CENT OF WATER																		
3	60.80	72.0	46.5	54.83	68.0	44.8	54.63	61.2	42.9	42.22	45.0	37.0	50.04	55.9	43.7	41.62	45.6	35.90
6	55.21	66.2	38.0	59.22	63.1	54.4	51.80	56.0	43.0	43.12	52.0	38.0	45.31	52.0	39.1	43.79	50.0	35.60
9	61.56	70.2	51.5	56.64	61.6	50.0	48.00	54.7	41.6	38.10	44.7	28.1	37.90	45.0	30.0	35.60	40.8	21.30
12	57.05	64.0	48.8	56.74	67.3	49.0	55.50	62.5	48.9	45.22	58.3	36.4	38.70	44.6	29.1	37.97	46.6	25.20
SLAKED IN 300 PER CENT OF WATER																		
3	40.60	50.1	33.2	44.71	54.2	35.1	53.27	59.1	42.9	48.35	54.6	41.0	46.00	51.5	40.0	47.92	56.7	48.10
6	45.68	50.4	33.2	49.37	59.4	38.5	51.13	58.5	42.4	46.94	57.0	40.0	43.65	51.0	38.5	45.79	51.0	37.10
9	44.90	52.6	35.8	45.25	58.5	38.0	50.69	54.9	45.1	48.53	55.1	44.7	38.94	45.0	29.2	50.50	54.8	47.10
12	42.55	53.2	22.7	50.25	57.8	35.7	62.58	73.6	49.4	49.03	57.7	43.2	39.37	46.9	25.5	45.01	48.5	40.20
SLAKED IN 400 PER CENT OF WATER																		
3	64.07	74.4	55.8	62.90	68.0	56.9	75.70	92.3	68.0	75.67	87.8	62.8	68.01	79.0	58.9	58.01	66.6	49.60
6	71.07	83.4	52.1	69.50	84.0	46.0	75.33	90.4	67.6	69.50	79.4	61.7	55.30	59.2	49.1	59.05	64.1	52.80
9	59.40	65.9	51.0	60.74	74.6	46.2	60.90	72.0	50.0	63.02	67.9	57.5	46.42	54.2	32.7	47.98	54.9	34 30
12	74.43	84.0	63.8	72.61	83.2	60.4	77.32	87.0	71.0	.....	....	....	49.74	53.9	42.3	54.67	61.2	45.60

The curves on plate VIII show that there is little change in strength after three months. In a few instances there is a slight gain, but in most cases the three, six and nine months' figures run close, followed, as a rule, by a falling off at the end of twelve months. Inspection will show that this falling off is most pronounced with the high ratios of sand, 4:1, 5:1, 6:1, where the decrease has frequently begun at the end of three months.

The diagrams according to percentage of water (Plate IX) are fairly uniform, all indicating a decrease in strength to 200 or 300 per cent followed by a rise with 400 per cent of water. This final rise seems erratic, and its meaning is not at present understood. It will be noted that the greater ranges between highest and lowest tensile strengths are found where the lower sand-lime ratios were employed.

Plate X brings out clearly the decrease in strength with increase in the amount of sand. This is most prominent in the lower percentages of water where a 1:1 mixture is the strongest. With the two higher percentages, 300 and 400, the average maximum strength is attained in the 3:1 and 4:1 mixtures. It is also conspicuous that the highest figures of all are reached with the lime when slaked with 100 per cent of water, which leaves it a dry powder.

MAGNESIAN AND DOLOMITIC LIMES.

Eagle Point, Iowa, Brown Lime.

The limestone from which this lime is manufactured comes from the Galena beds of the Ordovician. Its analysis is as follows:

Insoluble	8.65
Iron and aluminum oxide (Fe_2O_3 and Al_2O_3)	3.15
Lime (CaO)	29.00
Carbon dioxide (CO_2)	22.60
Magnesia (MgO)	17.12
Carbon dioxide (CO_2)	18.85
Water	.09
	99.46

Commercial product:

Insoluble	2.01
Iron and aluminum oxide (Fe_2O_3 and Al_2O_3)	6.60
Lime (CaO)	58.19
Magnesia (MgO)	33.48
Loss on ignition	slight
	100.28

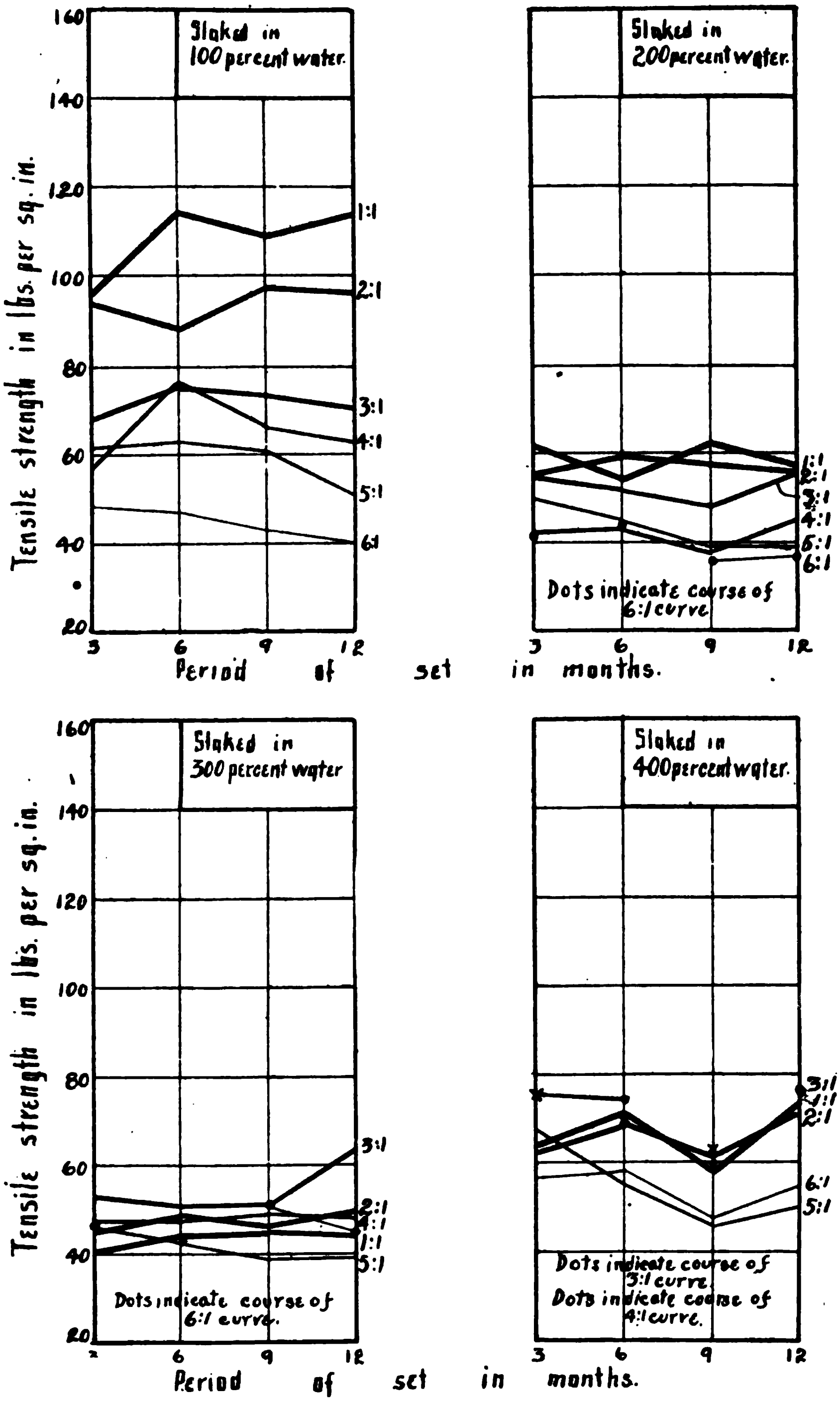

PLATE VIII.—Diagrams showing effects of different setting periods.

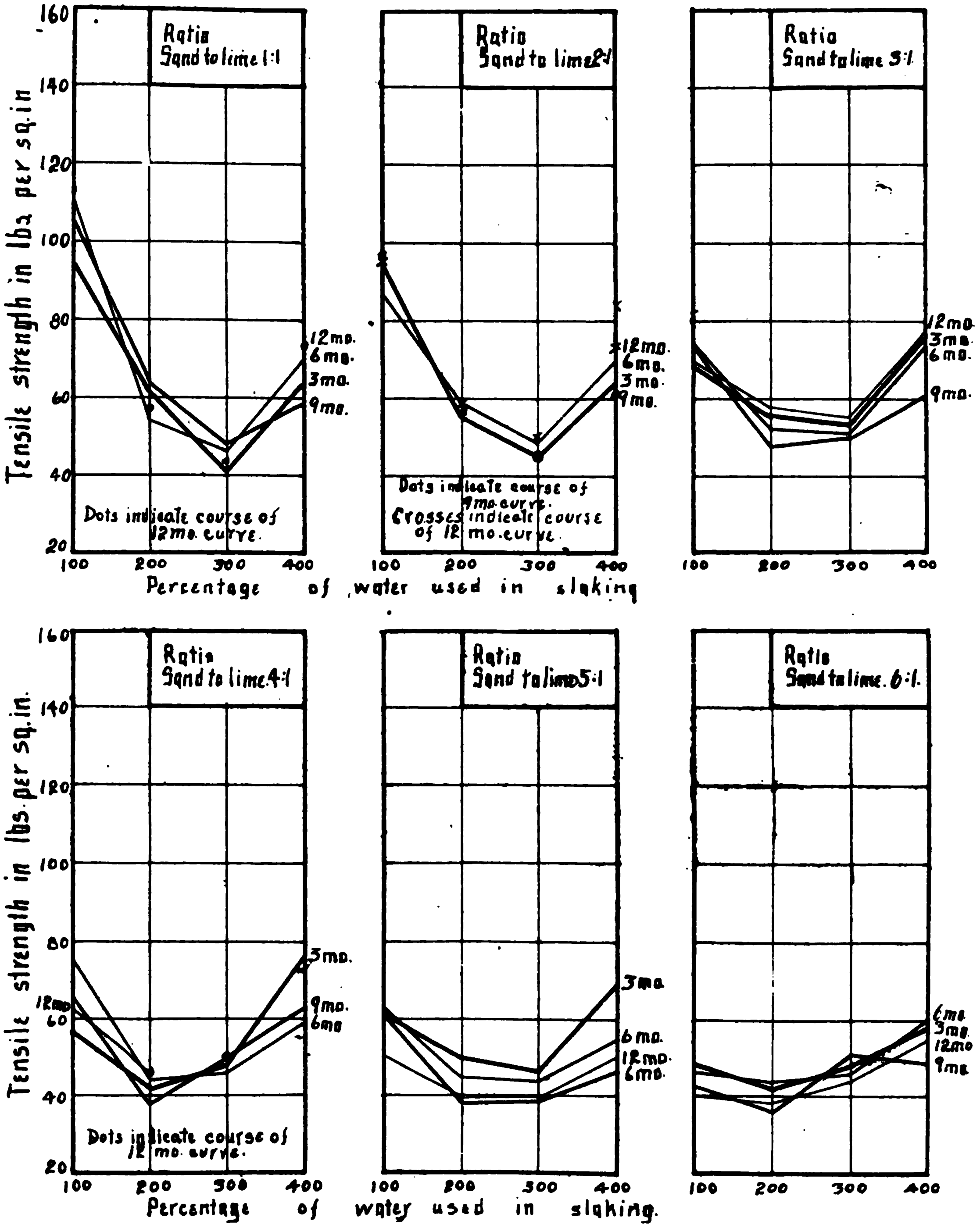

PLATE IX.—Diagrams showing effects of different percentages of water.

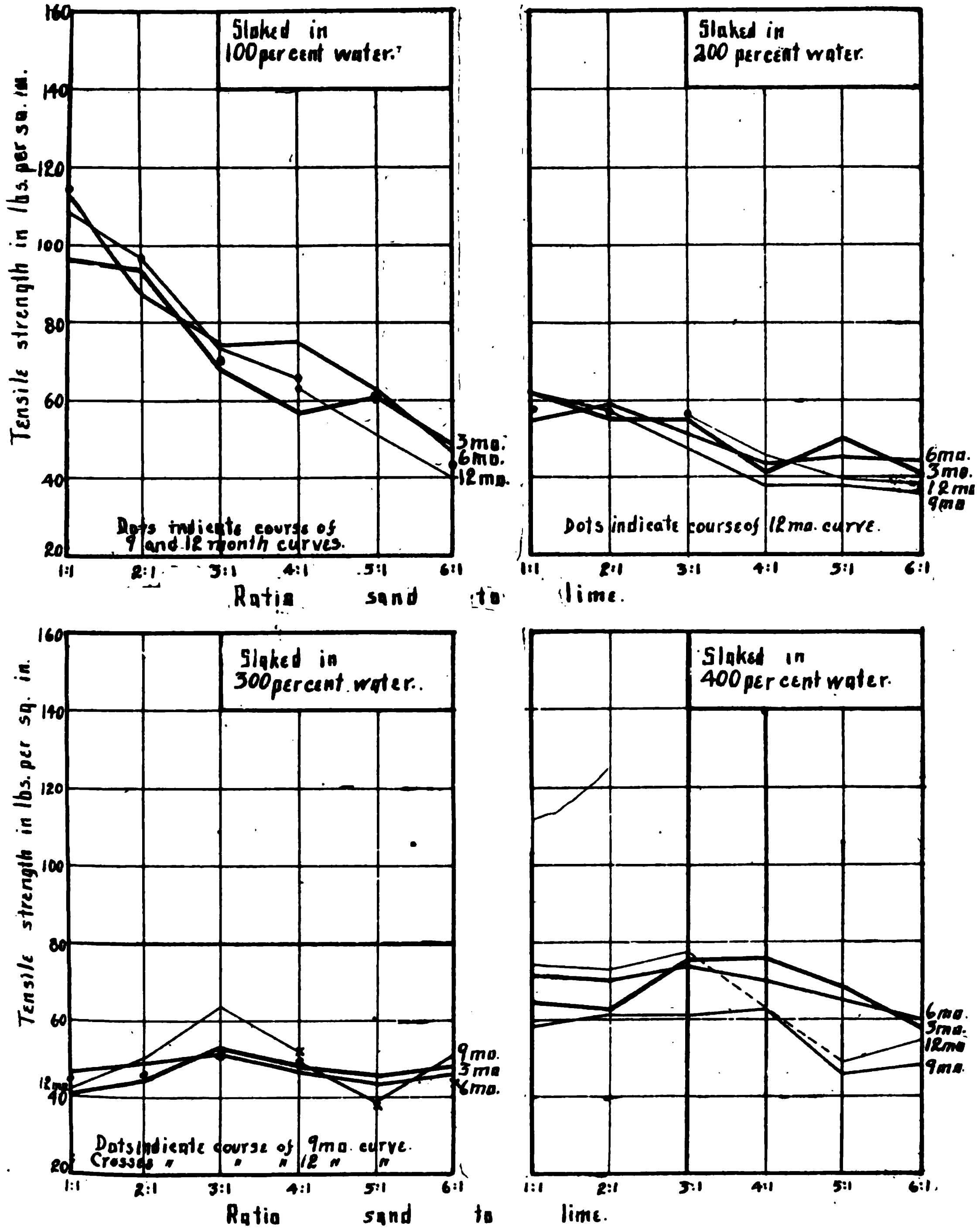

PLATE X.—Diagrams showing effects of different sand-lime ratios.

The Eagle Point lime slakes sluggishly and gives a paste of a brownish color. With all percentages of water employed there was little heating up, and no steam was generated. Slaking proceeded best with 200 per cent of water and more rapidly than with lower percentages. 100 per cent gave a stiff paste, 200 one of a readily and conveniently workable consistency, while the 300 per cent paste was thin, and required the removal of the excess of water before use.

Table III includes the results of the tests of this lime. On plates XI, XII and XIII are plotted the data of the table.

The curves on plate XI again bring out the decrease in strength with age. It will be observed that the maximum strengths are attained at six and nine months, and that this almost universally falls off for the one year period. This falling off is most pronounced in general in the case of the higher sand proportions.

The influence of the amount of water used in slaking is shown on plate XII. It is impossible to make any generalized statements from the diagrams. As a rule the highest strengths are found with the lower percentages of water. In the case of the 2:1, 5:1 and 6:1 sand-lime ratios, however, this is reversed and the 300 per cent gives the highest figures.

As with the white limes, the curves based on the sand-lime ratio are the most characteristic of the set. The lowest proportions of sand gave in all instances the highest results. The decrease in strength with increasing sand is decided and rapid. The greatest range is seen to be with the lower percentages of water, the maximum tensile strength being shown by the "powder" slaked lime.

MASON CITY, IOWA, BROWN LIME.

The Mason City stone is Middle Devonian and belongs to the Cedar Valley stage. Its chemical analysis follows:

Insoluble	1.34
Iron and aluminum oxide (Fe_2O_3 and Al_2O_3)	2.07
Lime (CaO)	33.54
Carbon dioxide (CO_2)	26.35
Magnesia (MgO)	16.99
Carbon dioxide (CO_2)	18.68
Moisture	1.03
	100.00

TABLE III.

EAGLE POINT BROWN LIME.

Time of set in months	Tensile Strength of Briquettes in Pounds per Square Inch.																	
	Sand to Lime 1:1			Sand to Lime 2:1			Sand to Lime 3:1			Sand to Lime 4:1			Sand to Lime 5:1			Sand to Lime 6:1		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
"POWDER SLAKED" IN ABOUT 75 PER CENT OF WATER.																		
3	88.85	120.0	73.0	94.90	110.0	80.0	90.92	104.8	66.7	84.26	98.0	74.0	72.60	82.5	60.0	57.30	61.0	55.8
6	157.90	176.0	130.0	99.60	125.0	75.0	106.67	116.2	95.2	90.97	104.9	80.0	73.32	92.8	63.9	57.50	66.0	50.0
9	155.30	181.2	130.1	96.50	105.0	82.0	96.95	107.6	74.3	74.89	81.9	66.7	78.62	93.1	66.3	64.78	77.0	52.0
12	159.03	182.8	120.1	99.10	119.7	76.5	98.82	112.7	89.5	68.91	92.1	49.5	69.90	84.8	57.6	47.39	56.3	34.3
SLAKED IN 100 PER CENT OF WATER.																		
3	110.70	135.0	85.0	100.04	110.0	82.5	90.41	100.0	80.0	80.67	96.8	60.0	80.40	96.0	70.0	50.70	55.0	40.0
6	148.54	169.4	116.3	96.51	103.9	75.0	95.90	122.0	84.0	82.60	93.0	68.0	74.28	87.6	47.6	50.43	56.4	39.6
9	154.08	208.2	119.7	113.31	132.0	97.1	94.38	110.0	71.4	87.90	104.9	72.8	86.20	98.4	63.7	62.20	72.8	52.4
12	135.88	159.4	105.2	107.32	127.5	89.6	93.08	110.1	80.2	73.85	92.2	50.5	70.71	88.1	63.1	49.10	58.4	39.6
SLAKED IN 200 PER CENT OF WATER.																		
3	97.70	115.0	70.0	89.90	109.0	72.0	100.60	105.9	95.1	64.60	73.5	61.0	67.90	79.2	54.5	62.31	75.0	53.0
6	87.54	97.0	73.3	78.11	92.7	68.6	85.94	97.2	64.5	55.10	62.5	40.4	73.27	87.2	58.8	57.72	62.1	48.5
9	112.66	124.5	94.1	87.96	110.0	85.0	104.05	113.2	89.6	66.40	75.5	58.8	72.48	87.4	59.2	65.80	75.0	55.7
12	90.46	107.2	73.5	85.31	99.0	75.0	80.88	90.4	67.3	57.70	65.7	50.5	73.38	84.4	60.2	59.58	67.0	52.4
SLAKED IN 300 PER CENT OF WATER.																		
3	119.85	145.0	101.1	112.16	126.3	93.7	86.80	98.0	70.0	73.57	81.6	70.0	80.10	100.0	68.0	68.87	77.0	60.0
6	124.25	132.4	103.0	113.21	132.4	94.2	86.50	101.0	74.3	78.31	92.4	70.5	88.92	101.0	77.7	78.12	84.2	70.3
9	140.24	160.0	125.0	114.12	126.6	100.1	99.19	120.0	79.1	81.24	92.6	71.1	87.02	95.1	75.7	74.25	90.2	56.0
12	134.40	152 0	105.9	111.95	119.2	101.0	91.60	98.0	75.7	79.17	95.0	66.0	70.71	88.1	50.5	66.16	75.2	58.4

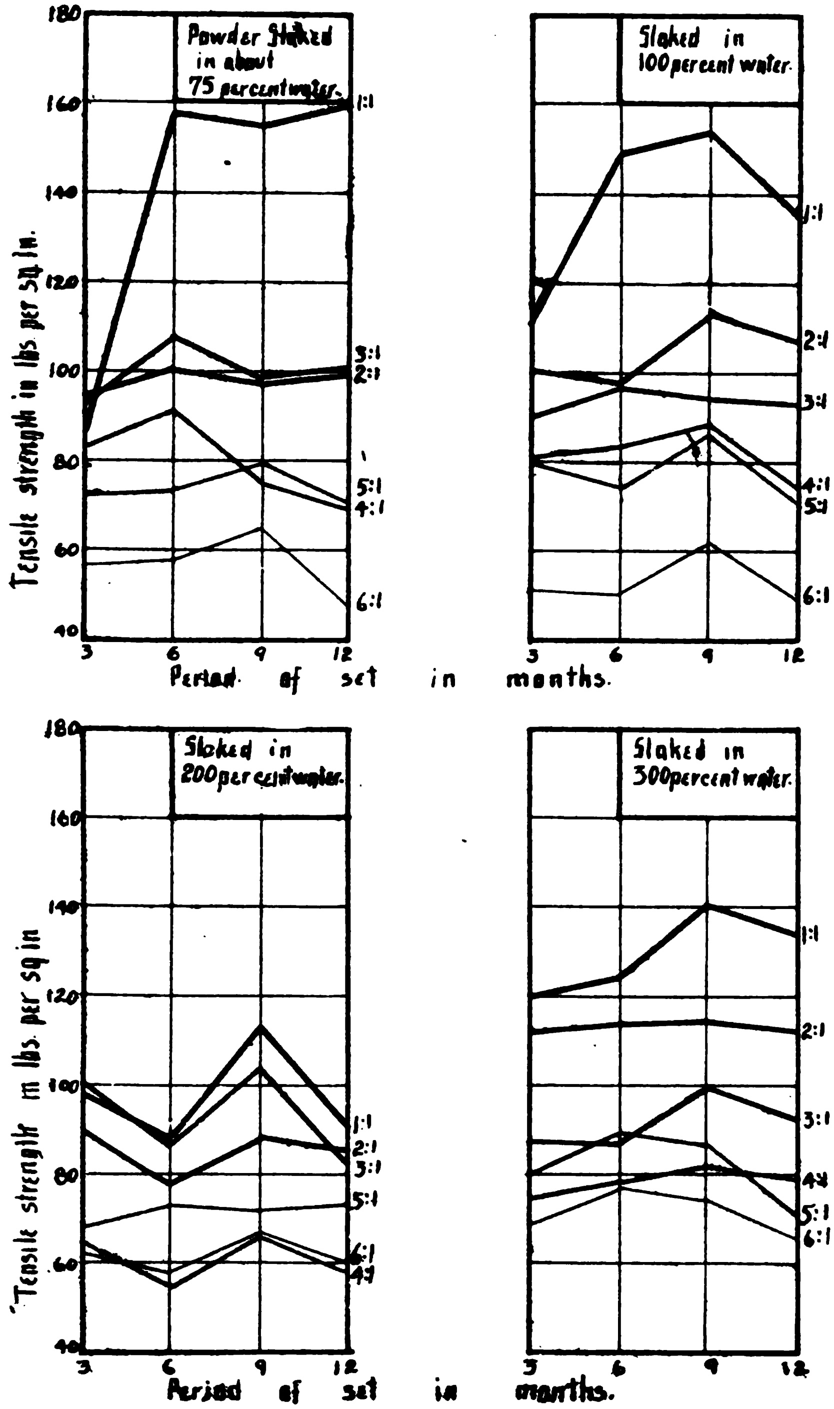

PLATE XI.—Diagrams showing effects of different setting periods.

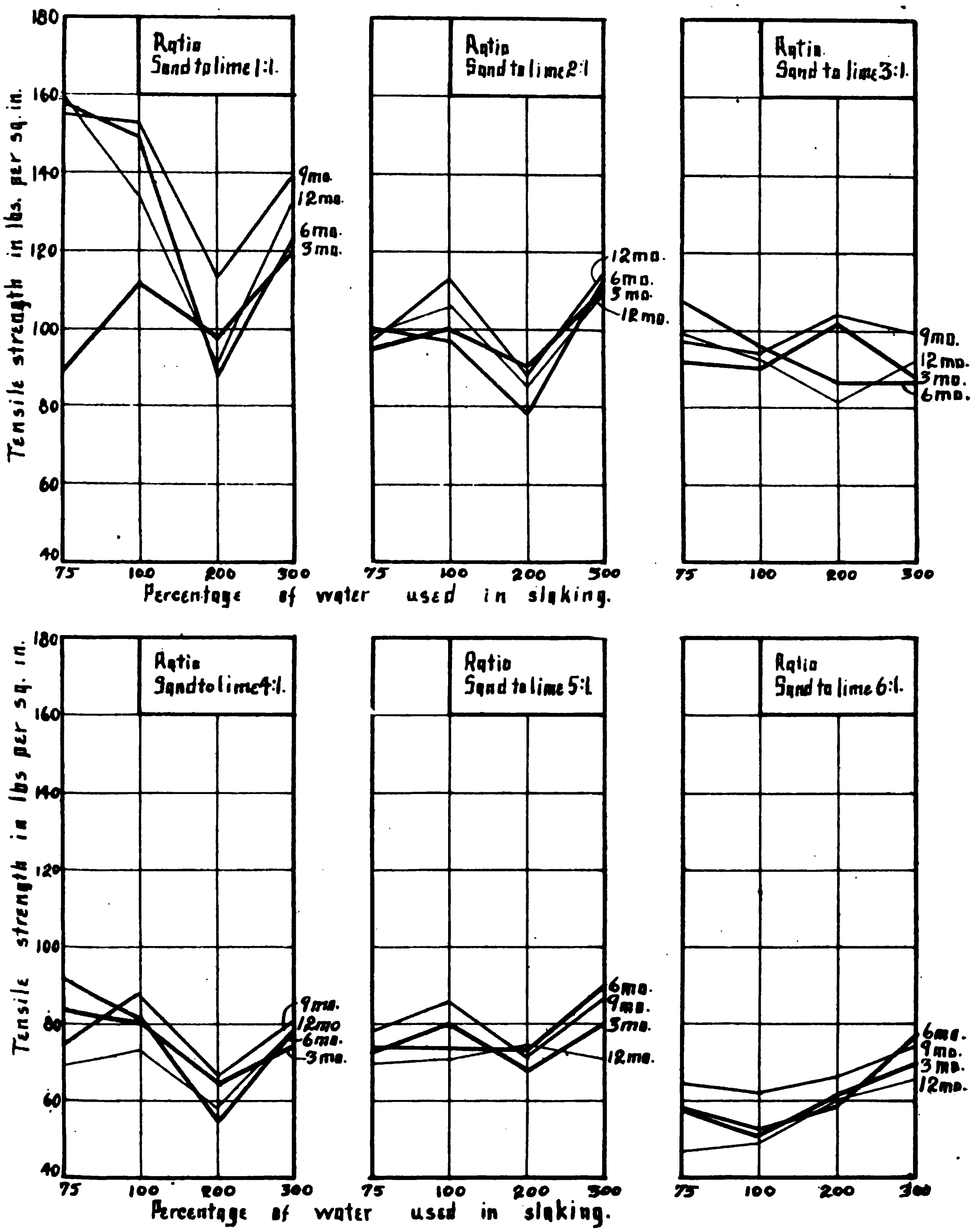

PLATE XII.—Diagrams showing effects of different percentages of water.

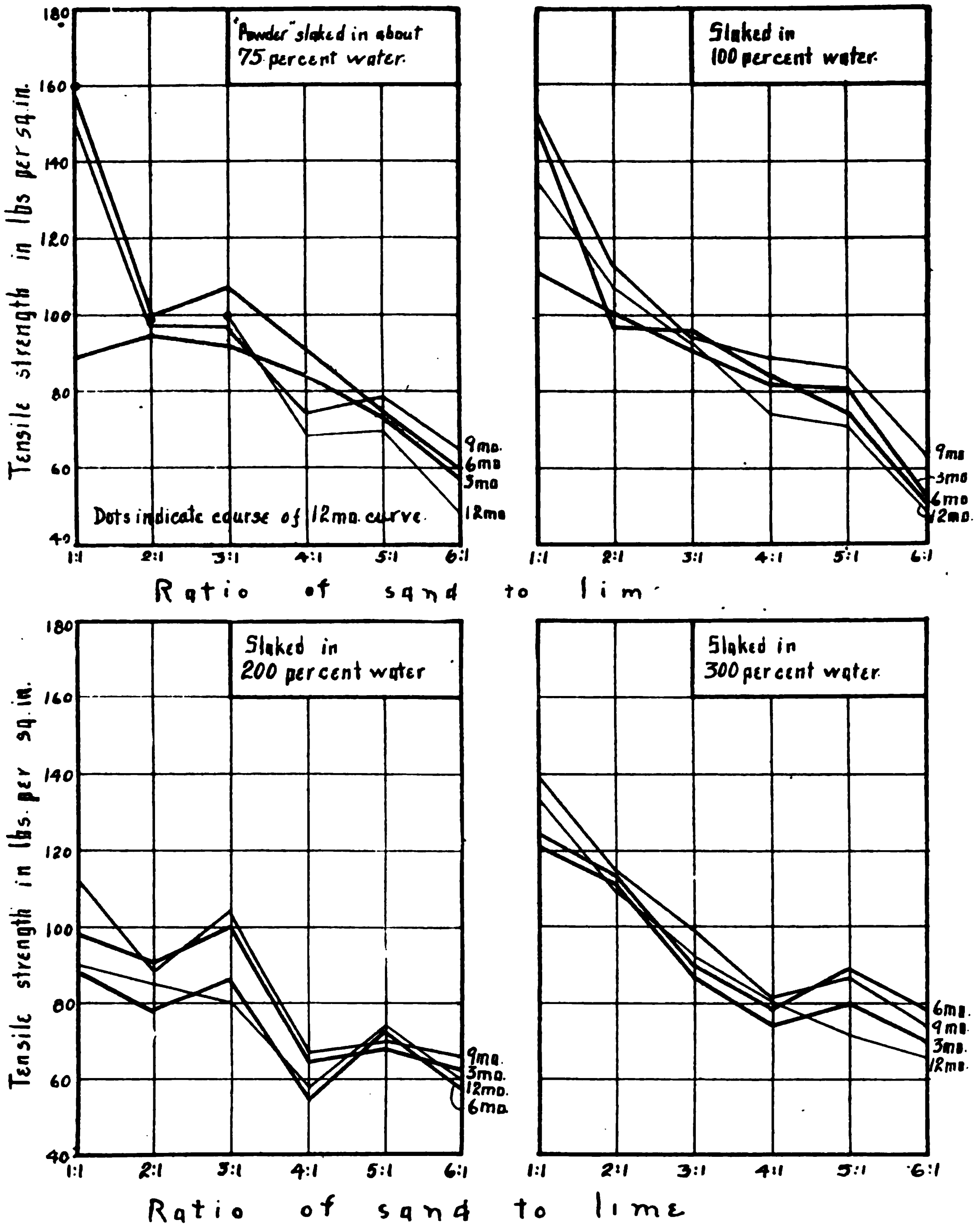

PLATE XIII.—Diagrams showing effects of different sand-lime ratios.

Analysis of the commercial product:

	Quick-lime	After slaking
Insoluble	2.32	.80
Iron and aluminum oxide (Fe_2O_3 and Al_2O_3)	6.03	9.80
Lime (CaO)	72.40	47.60
Magnesia (MgO)	15.23	19.20
Carbon dioxide (CO_2)	.10	3.50
Loss on ignition (CO_2)	3.36	18.70
	99.44	99.60

The Mason City lime slakes very slowly and considerable care was necessary to secure a uniform product free from lumps. By a proper adjustment of the amount of water supplied as it is needed, and its distribution throughout the mass by stirring, a homogeneous paste is, however, readily obtained.

In Table IV are arranged the data for this lime, which are also plotted on plates XIV, XV and XVI.

The curves on plate XIV show for the Mason City lime the same tendencies as do the corresponding curves on preceding pages. The diminution in strength with the longest time period, while not universal, is so common as to be unmistakable. This is more pronounced in cases where the higher proportions of sand are used.

Plate XV clearly shows the decrease in strength with increasing percentages of water. With few exceptions the maximum results come with the powder slaked lime from which the curves slope downward as the water percentages increase.

It will be noted also that the higher strengths correspond with the lower sand dilutions. With the powder slaked lime there is a decisive rise in all the curves at the 2:1 ratio and this is less prominently the rule with the other curves on the sheet. The length of the setting period appears to have no perceptible influence on this fact.

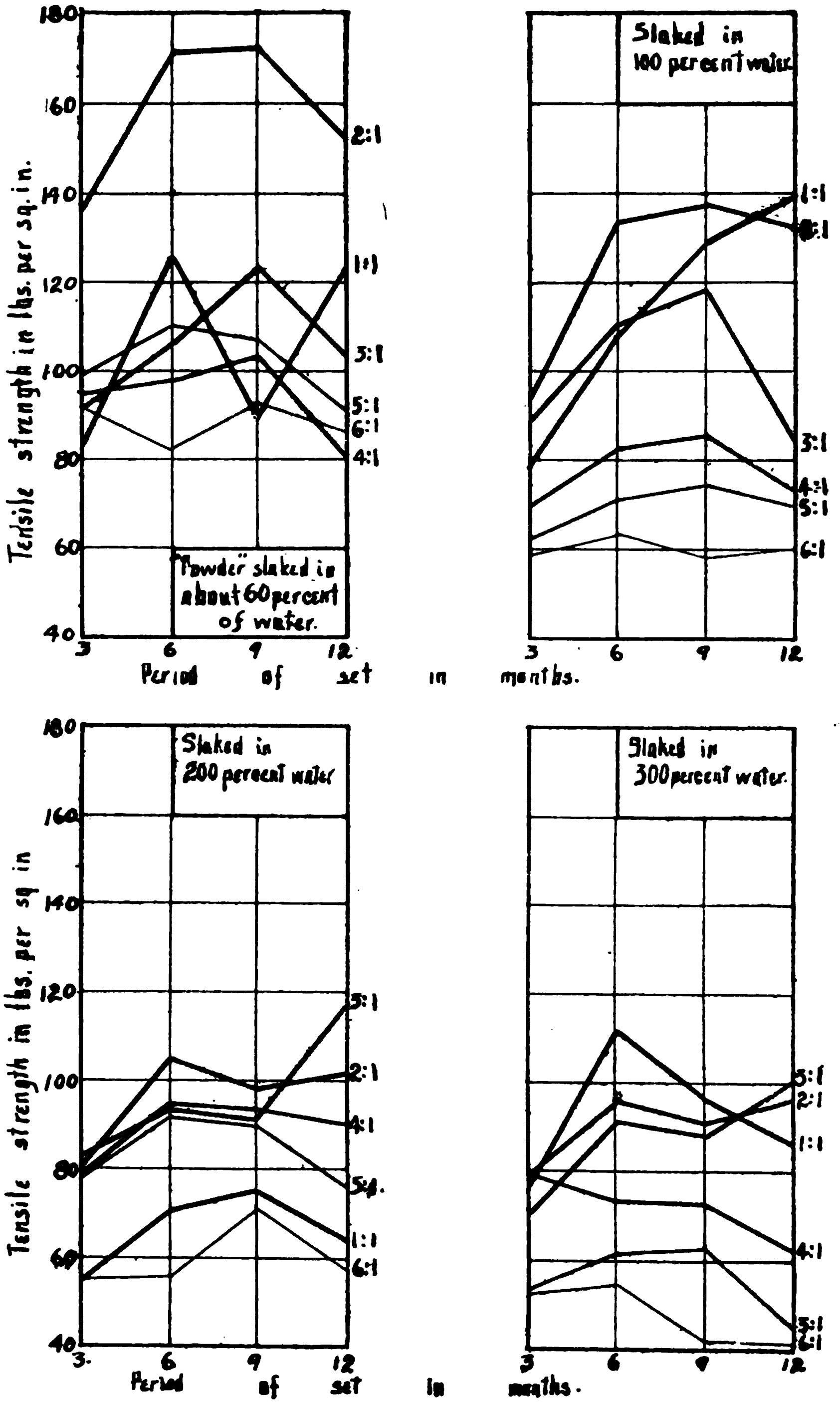

PLATE XIV.—Diagrams showing effects of different setting periods.

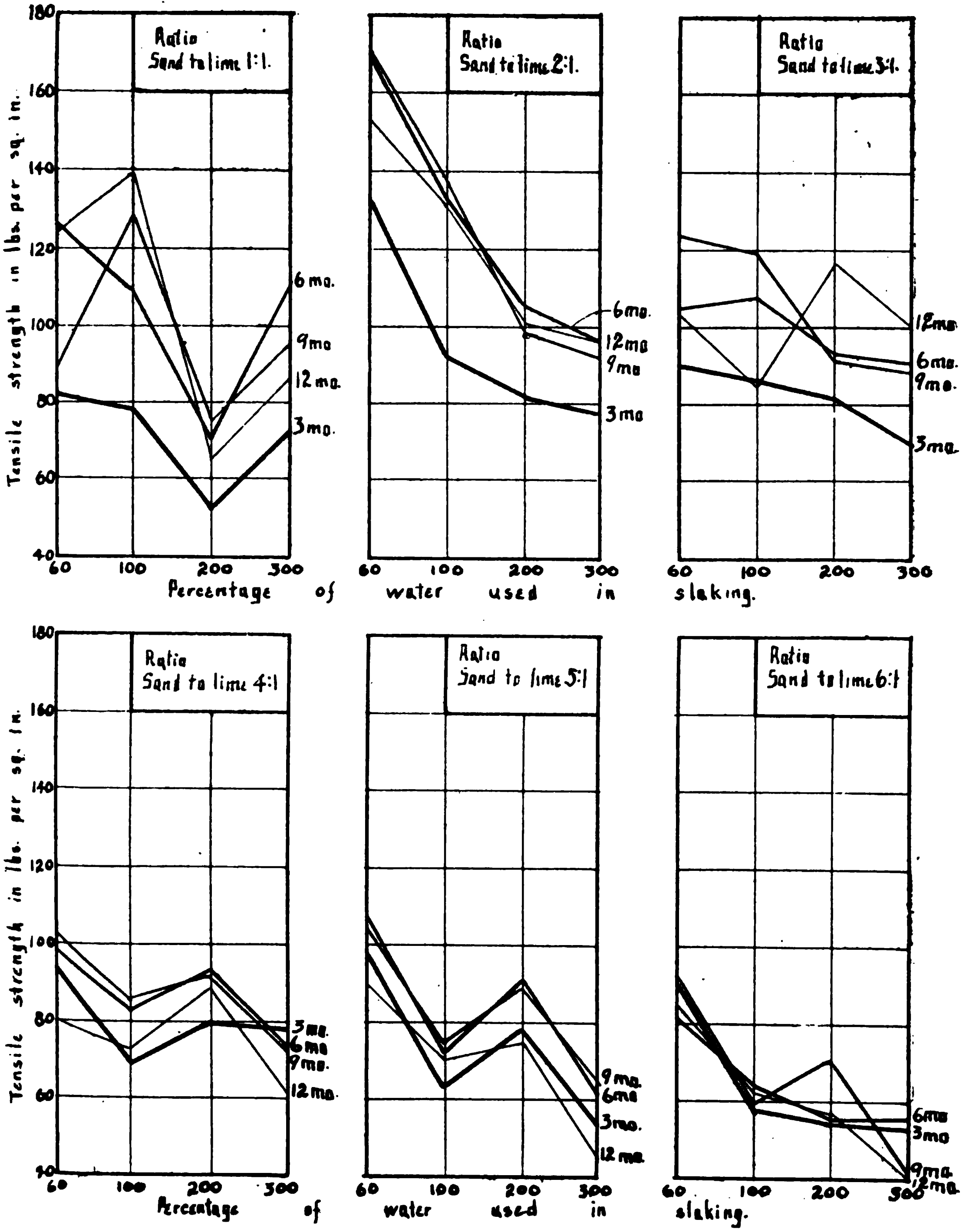

PLATE XV.—Diagrams showing effects of different percentages of water.

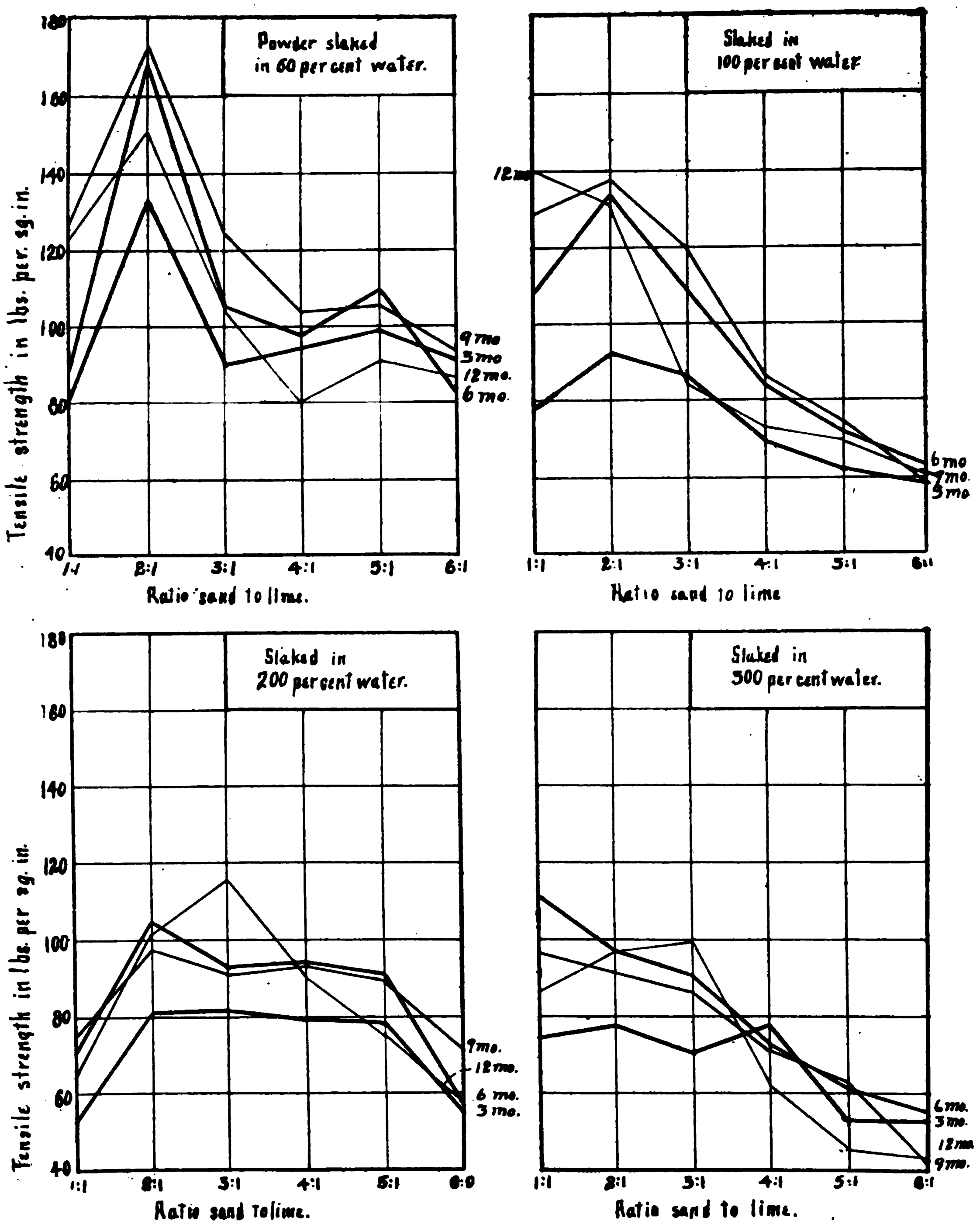

PLATE XVI.—Diagrams showing effects of different sand-lime ratios.

TABLE IV.

MASON CITY BROWN LIME.

Time of set in months	Tensile Strength in Pounds per Square Inch.																	
	Sand to Lime 1:1			Sand to Lime 2:1			Sand to Lime 3:1			Sand to Lime 4:1			Sand to Lime 5:1			Sand to Lime 6:1		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
"POWDER SLAKED" IN ABOUT 60 PER CENT OF WATER.																		
3	82.24	97.1	60.0	134.35	182.5	110.6	90.22	96.1	77.4	94.15	108.9	86.5	98.9	109.8	86.5	90.49	110.6	75.7
6	125.57	165.0	80.0	170.92	184.0	156.0	104.56	117.0	90.0	97.5	109.0	82.0	110.37	122.0	98.0	82.3	90.0	71.0
9	89.4	128.0	50.0	172.45	186.3	150.0	123.48	144.2	100.0	108.16	122.5	91.2	106.61	122.0	90.3	91.72	101.9	78.9
12	123.98	146.5	98.0	151.58	168.0	136.2	102.73	129.3	83.8	79.65	88.0	65.0	90.9	107.0	42.0	86.45	104.0	76.2
SLAKED IN 100 PER CENT OF WATER.																		
3	77.83	95.6	50.0	91.91	107.1	79.2	85.84	98.0	77.7	68.62	83.3	58.0	61.86	68.0	53.0	57.55	69.3	31.3
6	108.14	161.1	79.5	133.23	150.0	93.7	107.87	134.7	80.6	83.45	103.0	57.7	71.44	84.0	58.0	63.81	83.0	53.5
9	129.26	158.1	102.0	137.47	156.9	112.0	118.7	144.5	95.1	85.39	98.0	68.6	73.64	96.9	54.1	57.98	67.0	51.5
12	138.72	166.3	112.2	131.9	150.0	107.0	84.29	108.8	64.7	72.5	93.0	60.0	70.45	80.2	61.4	60.41	77.4	49.5
SLAKED IN 200 PER CENT OF WATER.																		
3	53.64	81.0	30.0	80.6	102.3	64.3	81.4	96.1	74.3	78.98	91.1	66.0	78.49	90.3	59.4	55.4	65.0	48.0
6	69.63	95.3	49.8	104.72	121.8	94.1	98.3	112.0	75.0	94.0	120.0	75.0	92.2	103.0	81.0	56.39	73.7	40.0
9	74.7	88.5	68.5	97.78	127.5	84.7	90.98	113.8	73.2	93.35	117.1	71.5	90.8	102.0	75.0	71.4	86.0	59.0
12	64.49	78.1	46.8	100.91	121.0	70.8	116.64	131.0	99.0	89.82	99.0	77.8	75.91	92.8	60.6	57.79	68.0	49.5
SLAKED IN 300 PER CENT OF WATER.																		
3	74.66	93.0	58.8	77.01	87.0	64.0	70.44	78.4	59.6	77.69	88.2	64.4	53.28	58.8	44.1	52.99	60.0	40.0
6	110.65	129.6	85.7	95.64	110.0	75.0	91.3	104.0	72.0	73.3	80.0	63.0	60.56	77.0	50.0	55.46	65.7	45.0
9	96.01	104.9	93.0	90.66	100.0	74.5	88.11	111.7	68.6	71.65	81.3	63.7	62.3	74.5	52.0	40.59	48.1	29.4
12	85.75	108.0	64.6	95.99	116.0	75.0	100.19	119.6	87.2	61.8	76.0	51.0	45.2	54.0	40.0	40.52	48.5	29.7

MAQUOKETA WHITE LIME, A. A. HURST & CO., MAQUOKETA, IOWA, DOLOMITIC LIME.

EXCELSIOR WHITE LIME, O. W. JOINER & SON, MAQUOKETA, IOWA, DOLOMITIC LIME.

The Maquoketa limes are produced from the Hopkinton beds of the Niagara stage. The composition of these strata is shown by the accompanying chemical analysis of samples from each of the companies:

	O. W. Joiner & Son.	A. A. Hurst & Co.
Insoluble	.51	.58
Iron and aluminum oxides ($Fe_2O_3 + Al_2O_3$)	.47	.36
Lime (CaO)	30.56	30.88
Magnesia (MgO)	21.54	21.56
Loss on ignition (CO_2 and water)	47.16	47.13

Analysis of the unslaked commercial product (A. A. Hurst & Co.).

Insoluble	.63
Iron and aluminum oxides ($Fe_2O_3 + Al_2O_3$)	2.10
Lime (CaO)	60.60
Magnesia (MgO)	35.73
Loss on ignition	2.30

The two samples of limestone analyzed come from the same horizon and compare very closely in composition. The treatment of the rock in the process of burning is exactly similar in both plants and the two limes are alike in appearance. Wood alone is used in the calcining process.

The quick-limes slake slowly, as is characteristic of the dolomitic limes, and the heat generated is relatively small in amount. The Joiner lime required somewhat less water for the first slaking than the Hurst product and, in fact, less than any of the other limes tested. This quantity, as shown in the table, is 50 per cent of the weight of quick-lime used. The results of the tensile strength tests of the two Maquoketa limes are compiled in tables Nos. 5 and 6 and are graphically represented by plates XVII, XVIII, XIX and XX, XXI, XXII, which follow:

TABLE V.

EXCELSIOR WHITE LIME, MAQUOKETA, IOWA.—O. W. JOINER & SON.

Time of set in months	Tensile Strength in Pounds per Square Inch.																	
	Sand to Lime 1:1			Sand to Lime 2:1			Sand to Lime 3:1			Sand to Lime 4:1			Sand to Lime 5:1			Sand to Lime 6:1		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
"POWDER SLAKED" IN ABOUT 50 PER CENT OF WATER.																		
3	109.68	136.0	85.0	121.62	140.0	111.6	95.65	115.0	78.4	98.9	115.7	81.0	98.61	111.6	78.4	73.63	80.9	68.0
6	118.12	134.3	100.0	137.18	174.8	103.9	117.33	130.4	107.8	108.92	137.2	85.3	103.10	115.5	91.2	75.21	84.5	67.0
9	169.61	196.0	139.3	158.72	194.1	133.3	119.76	132.0	100.0	112.34	120.6	104.9	109.71	119.4	101.9	84.26	94.2	72.8
12	171.53	193.4	151.0	158.36	173.5	141.6	108.56	124.3	98.2	105.4	116.0	92.0	90.94	108.8	58.8	72.14	84.3	63.7
SLAKED IN 100 PER CENT OF WATER.																		
3	110.59	127.5	91.8	99.5	105.0	93.3	83.5	97.0	78.0	83.59	95.1	65.0	51.71	64.1	38.8	61.4	77.0	50.0
6	130.7	154.6	113.4	118.91	136.3	100.0	91.01	100.0	83.6	96.05	117.1	78.4	64.1	79.6	56.3	69.15	82.5	55.3
9	129.9	147.0	114.0	118.1	135.0	102.0	84.4	95.0	65.0	91.4	99.0	86.0	64.0	69.0	60.0	60.3	71.6	52.0
12	132.09	144.5	120.1	111.21	124.3	101.0	80.21	93.9	58.6	78.17	84.1	65.3	45.24	57.3	34.6	54.74	64.4	45.5
SLAKED IN 200 PER CENT OF WATER.																		
3	83.0	95.0	70.0	97.02	115.0	84.1	102.29	108.0	95.1	72.66	85.0	60.0	70.9	78.4	55.9	65.47	74.0	52.0
6	109.5	133.0	77.0	130.89	150.6	118.5	119.84	134.6	104.7	83.85	98.0	73.0	75.82	80.6	74.2	78.86	98.0	63.7
9	117.7	127.0	96.0	113.08	133.3	88.6	113.65	139.1	100.0	84.8	100.9	67.3	72.3	76.9	67.3	79.5	100.0	53.9
12	99.38	120.2	82.8	113.31	130.5	87.3	89.72	106.8	78.9	62.16	75.2	56.4	67.7	82.0	44.0	65.54	76.0	57.4
SLAKED IN 300 PER CENT OF WATER.																		
3	134.33	157.3	117.8	102.71	122.4	85.0	98.42	110.0	91.0	80.8	88.0	73.0	68.31	78.4	60.0	63.31	73.5	52.9
6	138.32	168.2	111.7	115.49	136.0	103.0	99.67	107.9	88.3	91.6	107.0	85.2	86.61	103.9	76.7	77.27	84.2	71.3
9	131.82	153.1	106.2	115.52	130.0	95.0	89.98	115.4	94.2	88.07	92.3	72.1	84.91	101.0	69.2	69.49	87.7	57.7
12	134.87	147.0	118.1	92.91	111.8	64.4	90.66	97.2	77.7	77.67	94.2	49.0	60.89	71.3	49.5	62.59	69.9	48.5

TABLE VI.

MAQUOKETA WHITE LIME, MAQUOKETA, IOWA.—A. A. HURST & COMPANY.

Time of set in months	Tensile Strength in Pounds per Square Inch.																	
	Sand to Lime 1:1			Sand to Lime 2:1			Sand to Lime 3:1			Sand to Lime 4:1			Sand to Lime 5:1			Sand to Lime 6:1		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
"POWDER SLAKED"—ABOUT 70 PER CENT OF WATER.																		
3	112.6	135.0	70.0	143.87	157.7	117.5	121.58	133.0	115.4	105.29	120.0	100.0	104.74	130.0	85.0	98.39	115.7	88.2
6	140.05	197.0	100.0	213.52	243.9	178.2	125.0	141.0	102.0	115.38	133.6	97.0	126.38	142.9	108.1	110.81	125.00	93.1
9	159.38	176.7	145.2	191.56	214.8	170.1	125.83	139.2	110.8	131.45	144.1	124.5	113.53	138.8	90.7	102.47	115.7	90.2
12	150.08	180.6	121.8	182.98	210.0	158.0	129.89	147.5	108.9	122.16	146.5	96.0	118.26	138.6	78.4	104.70	118.0	87.0
SLAKED IN 100 PER CENT OF WATER.																		
3	128.43	144.0	110.0	130.14	153.0	110.0	130.0	140.0	120.0	115.93	126.2	100.0	101.64	111.7	86.5	97.66	110.6	82.5
6	178.95	204.1	151.0	156.75	177.0	144.9	143.36	173.4	120.0	134.16	158.4	120.8	123.92	142.2	109.8	105.92	121.6	98.0
9	184.29	213.2	150.0	167.36	183.6	146.9	154.3	168.0	137.0	144.5	162.0	111.0	137.56	152.4	125.7	119.94	140.6	105.8
12	185.85	212.2	164.8	157.91	170.0	130.9	144.47	161.6	132.3	123.05	133.7	94.9	128.16	137.4	117.1	108.1	116.0	96.0
SLAKED IN 200 PER CENT OF WATER.																		
3	106.01	120.0	80.0	105.09	136.5	89.1	99.82	121.0	88.0	91.04	110.6	87.7	103.62	120.0	85.0	87.72	90.0	74.8
6	134.66	163.2	117.0	125.20	151.5	101.0	108.18	125.7	93.9	96.85	115.7	73.5	106.53	117.3	93.1	83.4	100.9	65.7
9	152.84	173.4	131.6	124.70	141.6	96.8	108.3	120.0	93.0	94.54	115.0	84.5	85.26	95.2	77.7	92.1	99.0	82.7
12	146.05	164.9	121.6	114.51	145.3	89.7	102.34	111.2	93.9	101.1	112.1	87.9	97.18	118.2	70.7	95.19	112.1	82.0
SLAKED IN 300 PER CENT OF WATER.																		
3	100.7	125.0	90.0	86.49	94.1	70.0	82.25	95.0	63.7	....	....	....	....	....	....	....	....	....
6	126.8	134.0	115.0	98.07	117.0	84.2	95.50	113.8	89.1	....	....	....	....	....	....	....	....	....
9	123.22	136.7	113.2	112.6	136.0	95.0	95.90	108.0	85.2	....	....	....	....	....	....	....	....	....
12	124.9	138.1	113.4	99.27	131.9	79.3	91.91	114.3	78.6	....	....	....	....	....	....	....	....	....

Joiner lime.—Plate XVII brings out very well the change in strength with increasing period of set. The powder slaked lime attains its maximum strength at nine months with the marked exception of the 1:1 ratio in which case the curve continues upwards to the end of a year's time, and gives the highest figure of any mixture in the set. The other percentages of water give characteristic and fairly uniform curves, showing a maximum strength at six to nine months and a falling off or weakening after nine months' set.

The curves on plate XVIII are somewhat irregular but exhibit quite clearly the decrease in strength with increase of water for slaking. In general, the slope is down from the "dry" slake through all higher percentages, although, in a number of instances, there is an unaccounted-for rise from the minimum at 100 or 200 per cent. The position of the curve groups on the diagrams indicates the lowering strength with larger sand dilutions.

Plate XIX emphasizes the weakening effect of sand dilutions higher than 1:1 and 2:1 mixtures. In the majority of instances even proportions of sand and lime afford the greatest strengths, although a higher figure for 2:1 is not unusual. Higher ratios than these two, however, produce a marked falling off in tensile strength for all four time periods.

Hurst lime.—The curves of plate XX run conspicuously uniform and show in general, the greatest strength at nine months. The usual lowering in strength at the end of twelve months is to be noted. As a rule this lime attained its maximum strength with 100 per cent of water as shown on sheet XXI. The highest figures of the set are reached, however, by the powder slaked lime and a sand-lime ratio of 2 to 1.

On plate XXII is brought out the relation between the strength and amount of sand used. With the powder slaked lime, 2:1 gives the highest results, while with the other percentages of water for slaking the trend of the curves is universally downwards as the sand increases.

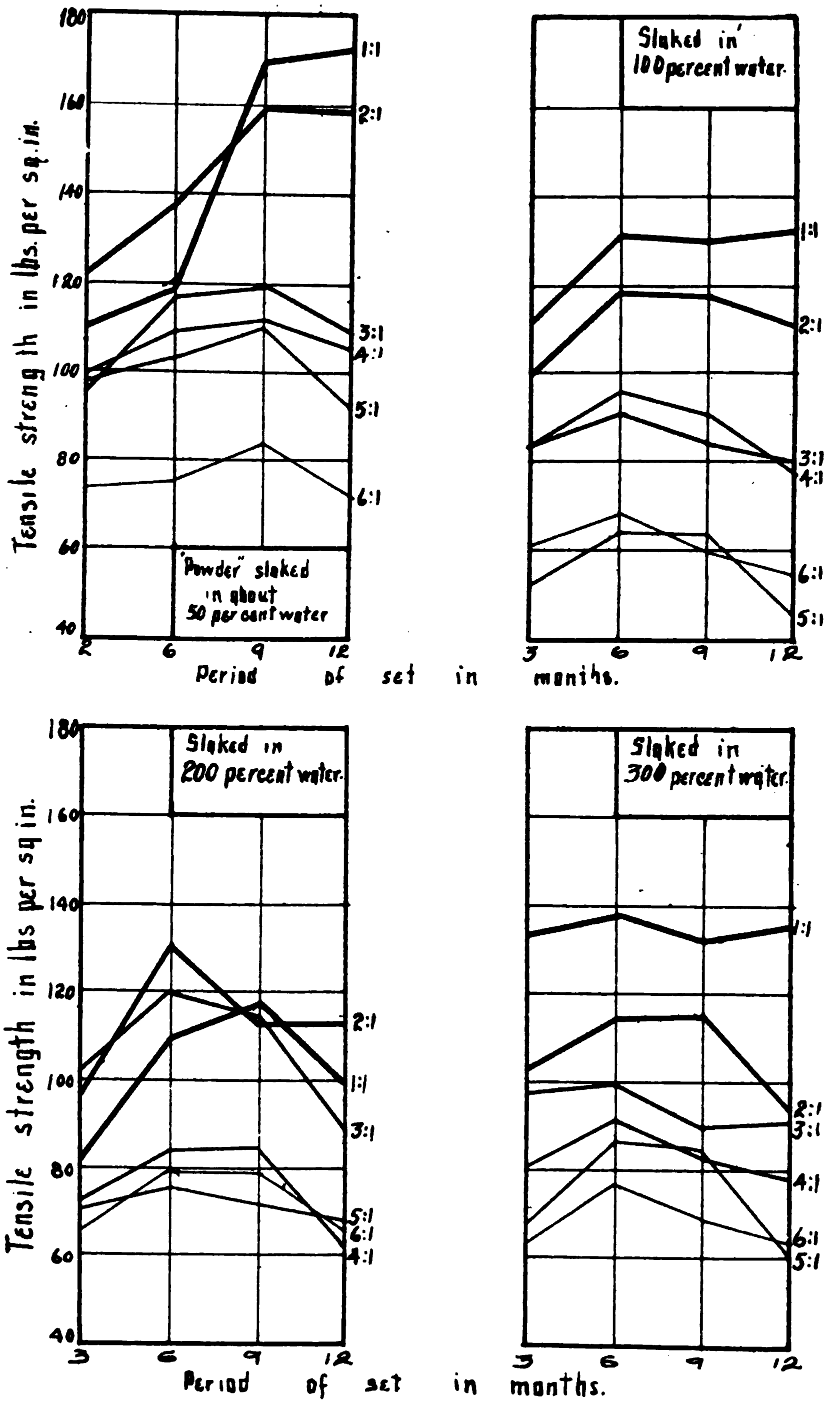

PLATE XVII—Diagrams showing effects of different setting periods

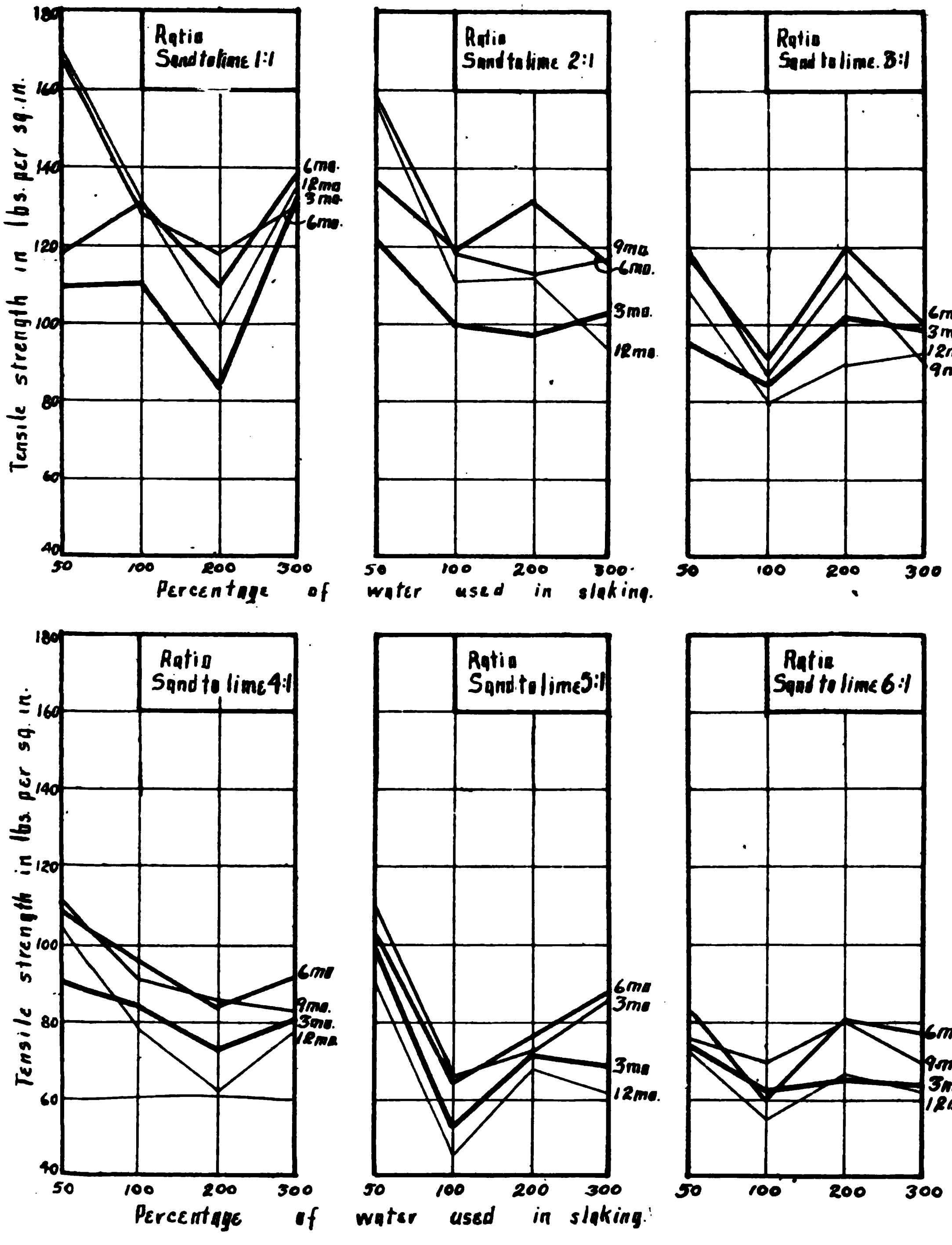

PLATE XVIII—Diagrams showing effects of different percentages of water.

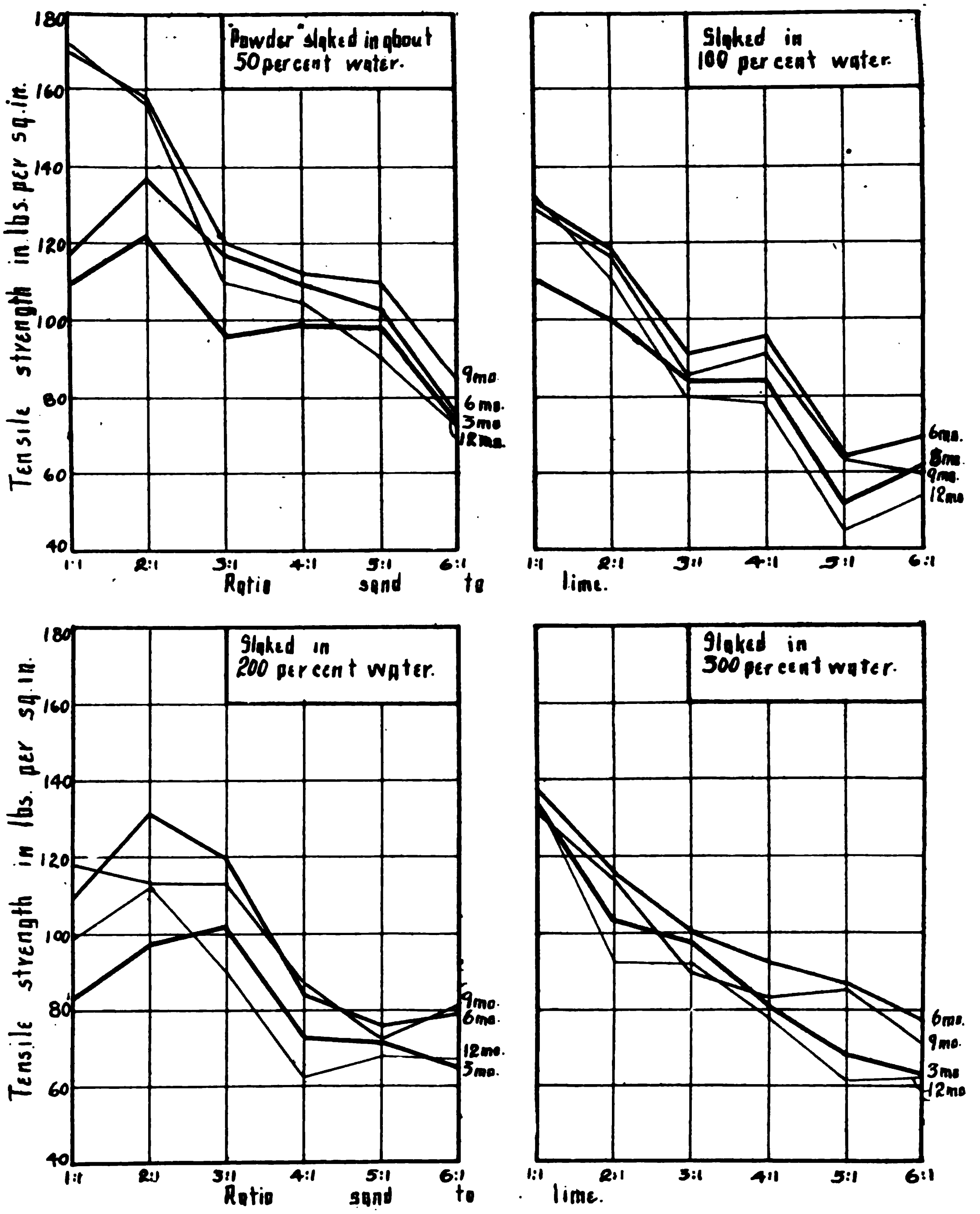

PLATE XIX—Diagrams showing effects of different sand lime ratios.

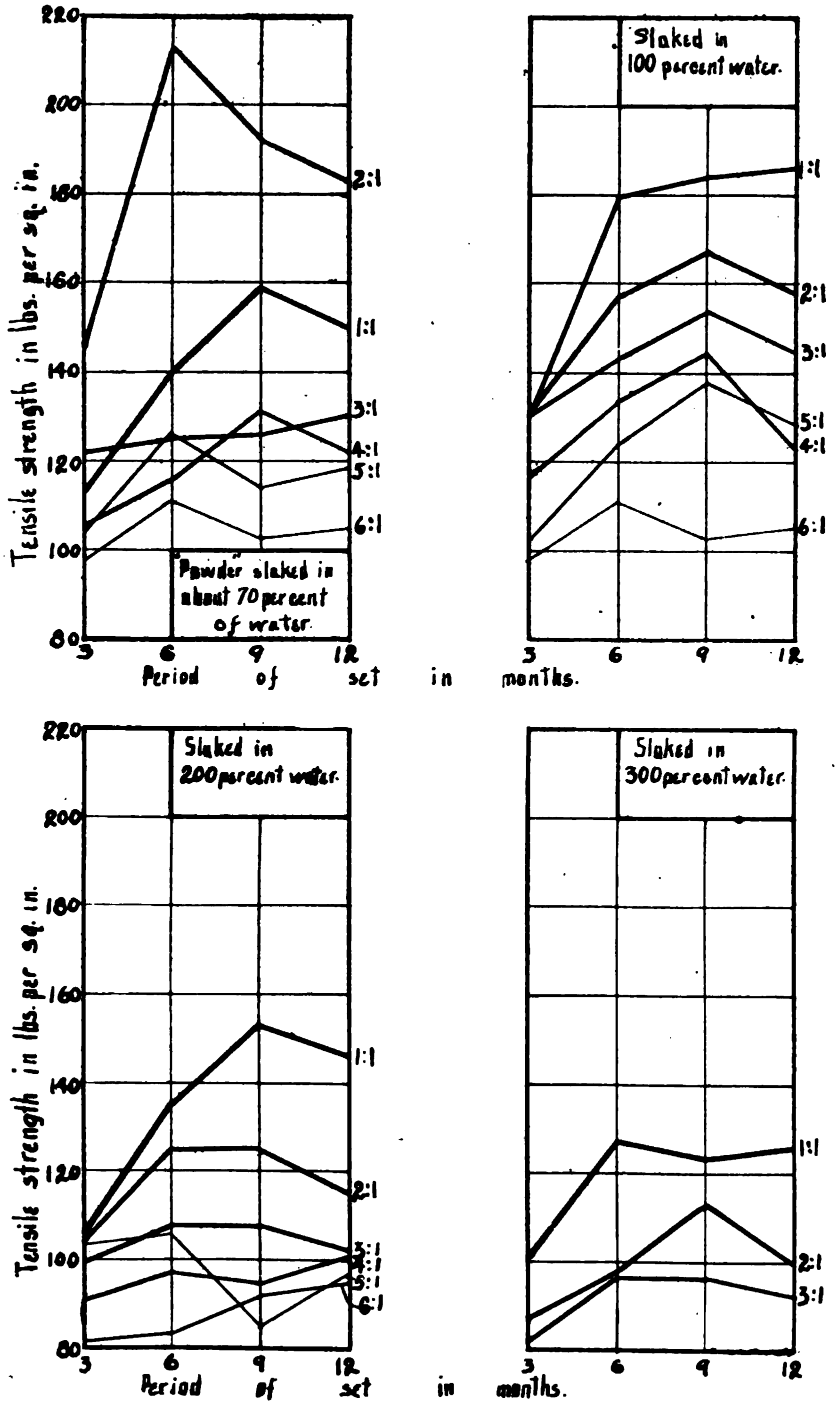

PLATE XX—Diagrams showing effects of different periods of setting.

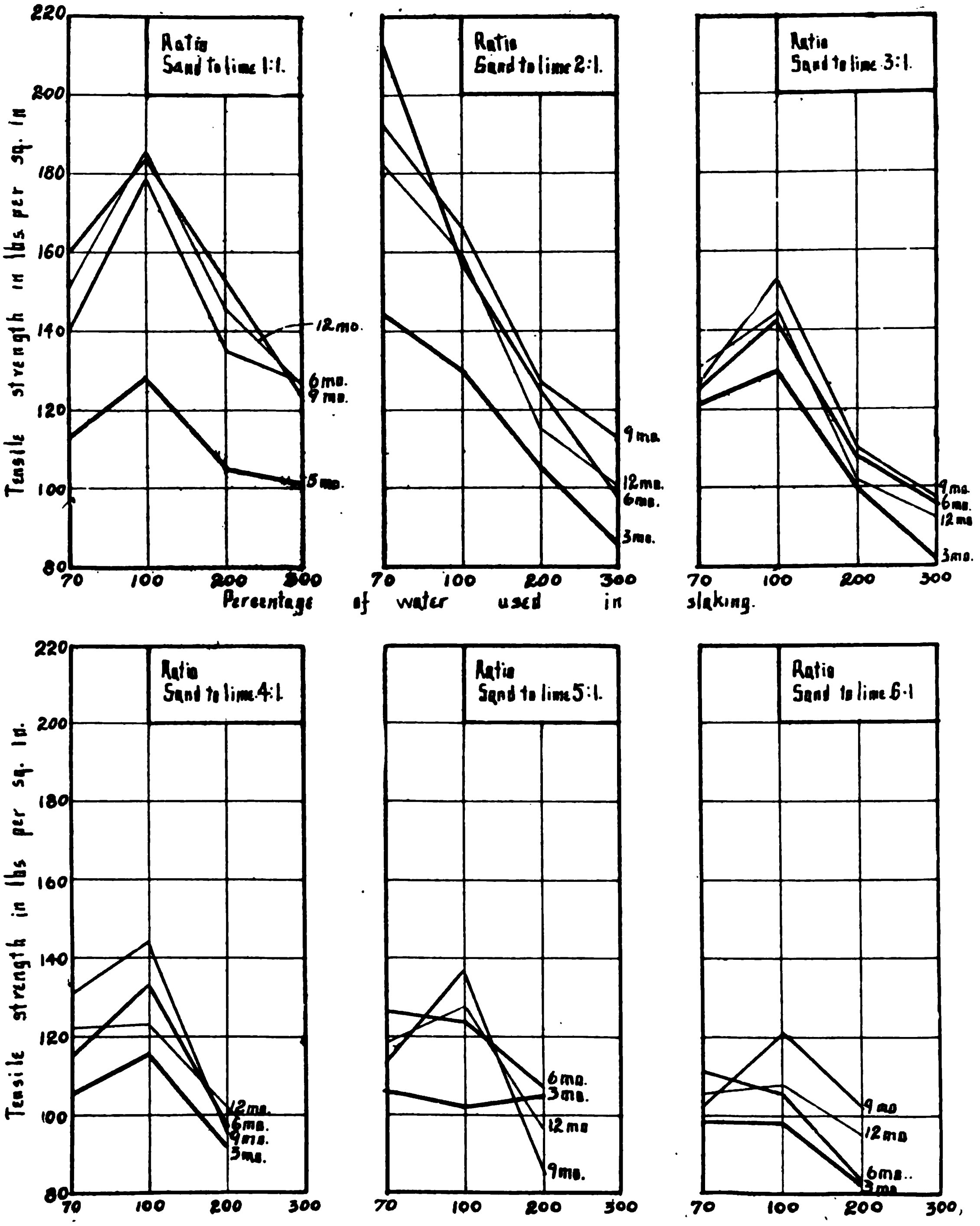

PLATE XXI—Diagram sshowing effects of different percentages of water.

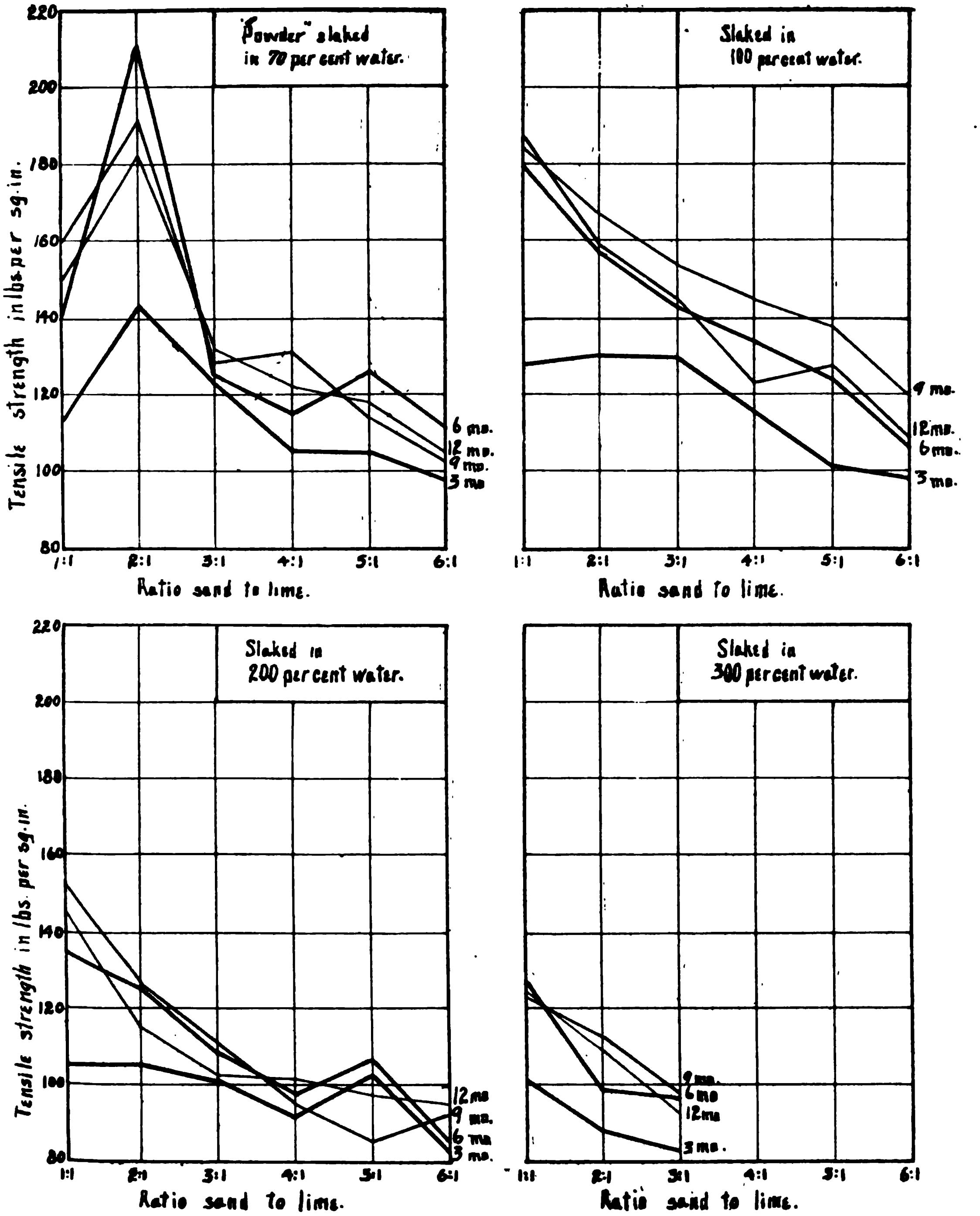

PLATE XXII—Diagrams showing effects of different sand-lime ratios.

NEW PROCESS LIME, VIOLA LIME WORKS, VIOLA, IOWA.

The Viola lime was manufactured from the Le Claire beds of the Niagara stage. The plant is now idle. The stone is highly magnesian and produces a lime of the following composition:

	Quick-lime.	After slaking.
Insoluble	1.20	1.00
Iron and aluminum oxides ($Fe_2O_3 + Al_2O_3$)	1.40	1.00
Lime (CaO)	66.80	45.20
Magnesia (MgO)	27.10	29.28
Carbon dioxide (CO_2)	.70	2.02
Loss on ignition, less CO_2	2.50	21.75
	99.70	100.25

The commercial product takes water slowly and no slaking action becomes noticeable for some time. About five hours was required for complete slaking in 60 per cent of water, the mixture heating but slightly. With the higher percentages of water the time required is still greater and in all cases the slake is very cool. The lime does not melt to a paste as is usual, but remains in a more or less granular condition. The results of the tests of the Viola lime are tabulated in Table VII and plotted on plates XXIII, XXIV and XXV.

A comparison of the data obtained in these tests with the results from the other limes of the whole series reveals two notable departures. The breaking strengths are on an average higher, the maximum being nearly 50 per cent greater than the closest competitive value. They are remarkable also in that the strength almost without exception increases to the end of twelve months and this increase is most rapid, as shown by the sharpness of the curves on plate XXIII, when slaked with 100 per cent of water, which gives the highest breaking strength of the set. The steepness of the curves between nine and twelve months is in many instances so marked as to render of extreme interest the question, how long such an increase would continue. A properly designed series of tests should be made along this line.

Plate XXIV shows that the lime develops its greatest strength when slaked in 100 per cent of water, while on XXV is plainly shown the decrease in tensile strength following the addition of proportions of sand greater than one and two to one of lime.

TABLE VII.

VIOLA "NEW PROCESS LIME."

Time of set in months	Tensile Strength in Pounds Per Square Inch.																	
	Sand to Lime 1:1			Sand to Lime 2:1			Sand to Lime 3:1			Sand to Lime 4:1			Sand to Lime 5:1			Sand to Lime 6:1		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
"POWDER" SLAKED IN ABOUT 60 PER CENT OF WATER.																		
3	116.5	138.7	104.0	130.8	152.0	100.0	107.2	122.6	89.6	101.9	113.4	92.3	103.7	120.7	88.0	81.5	91.5	75.4
6	149.5	168.6	124.5	149.4	174.5	122.4	139.8	163.2	117.0	122.9	152.8	102.9	113.9	134.2	90.7	84.6	95.4	74.1
9	119.6	142.1	95.2	134.8	157.7	110.3	122.4	150.0	103.9	110.8	124.2	92.2	94.8	108.4	82.2	77.6	85.7	61.9
12	....	....	....	163.5	184.7	138.8	151.7	176.0	120.2	125.2	140.3	107.6	113.6	122.6	102.8	93.3	107.7	83.7
SLAKED IN 100 PER CENT OF WATER.																		
3	156.4	199.0	106.05	167.7	198.0	132.0	127.3	163.2	105.0	148.4	180.6	116.5	120.7	140.1	102.8	....	....	....
6	154.2	200.0	132.3	211.4	244.9	176.5	175.4	208.0	100.0	163.1	212.0	130.0	120.3	143.5	92.6	....	....	....
9	200.4	269.5	145.0	209.2	253.0	180.6	186.8	213.1	163.6	158.3	185.1	144.5	111.2	127.6	83.8	....	....	....
12	282.1	301.9	255.6	249.7	278.2	191.6	183.9	206.1	165.9	161.6	178.4	151.9	127.2	150.0	103.7	....	....	....
SLAKED IN 200 PER CENT OF WATER.																		
3	145.7	185.4	103.0	135.8	157.0	112.0	111.0	124.2	95.1	72.1	100.9	70.5	65.1	71.4	57.1	72.1	89.4	63.4
6	160.4	202.0	111.1	164.8	189.3	140.0	137.7	182.5	107.0	93.4	105.6	80.2	75.1	95.3	75.4	67.0	77.6	56.1
9	157.9	185.9	121.3	153.4	173.5	142.6	134.0	159.2	118.6	97.9	122.3	87.4	74.4	83.0	66.3	69.1	77.6	60.6
12	165.1	189.5	142.7	149.6	161.6	127.3	153.1	176.5	128.9	105.7	118.4	90.2	88.4	102.8	78.6	74.3	88.8	65.7
SLAKED IN 300 PER CENT OF WATER.																		
3	118.4	143.0	102.0	143.8	159.6	114.3	119.7	132.7	106.3	84.1	90.7	77.8	90.4	107.6	60.0	83.5	91.5	75.4
6	155.7	187.7	118.5	159.8	181.5	132.4	110.1	128.0	86.9	90.8	104.8	78.2	91.3	103.8	76.9	78.7	87.7	70.7
9	144.1	182.3	94.6	154.5	166.7	133.2	97.9	114.0	84.1	78.8	101.9	46.7	92.9	103.9	81.5	73.5	87.5	56.7
12	206.9	229.0	165.0	176.2	210.9	153.0	101.2	128.4	85.9	107.7	119.2	83.7	90.0	101.9	80.6	90.2	99.0	76.9

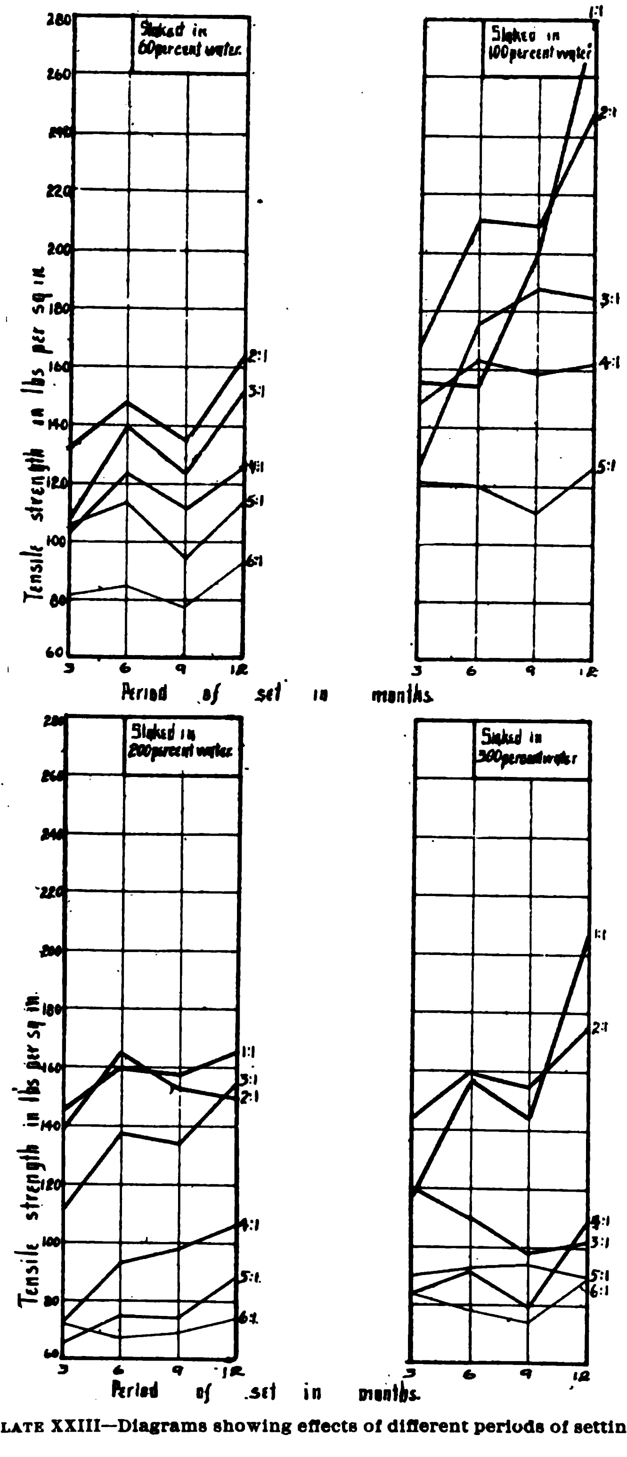

PLATE XXIII—Diagrams showing effects of different periods of setting.

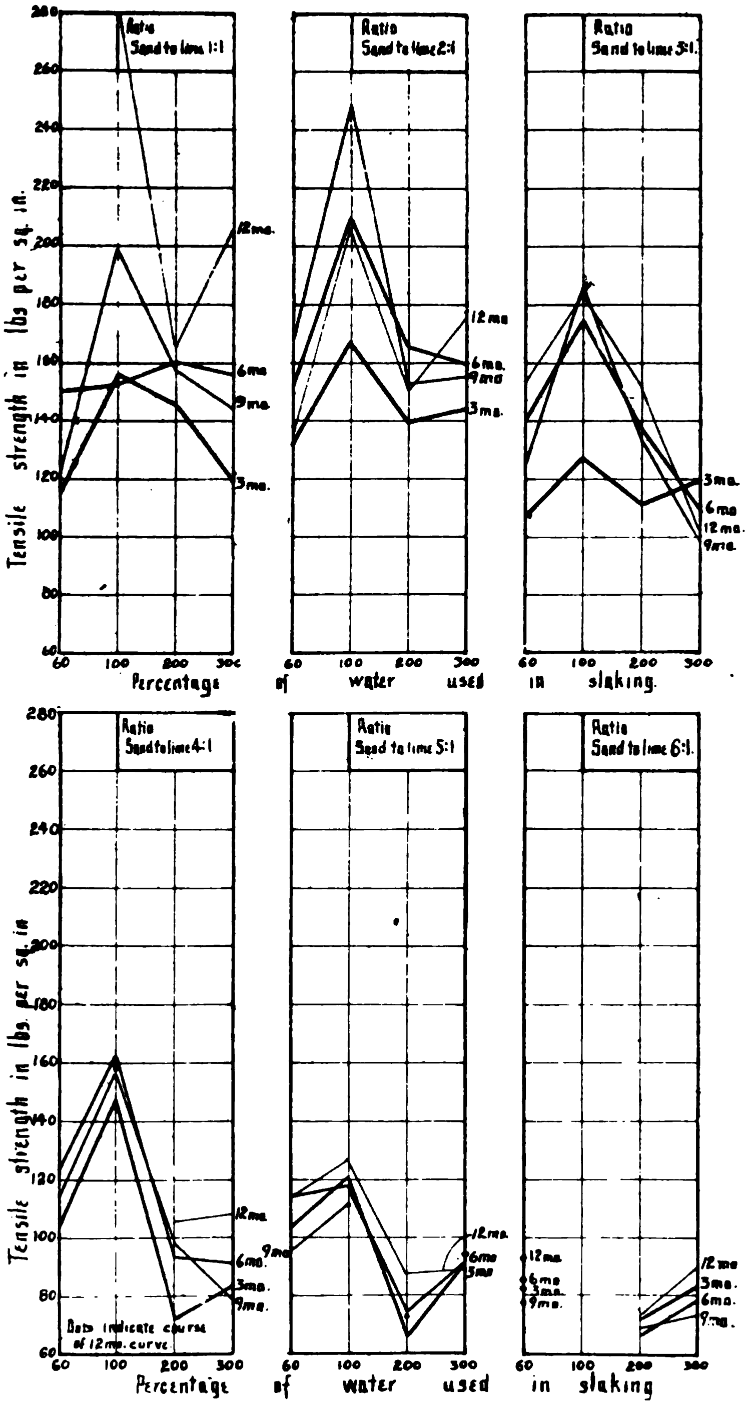

PLATE XXIV—Diagrams showing effects of different percentages of water.

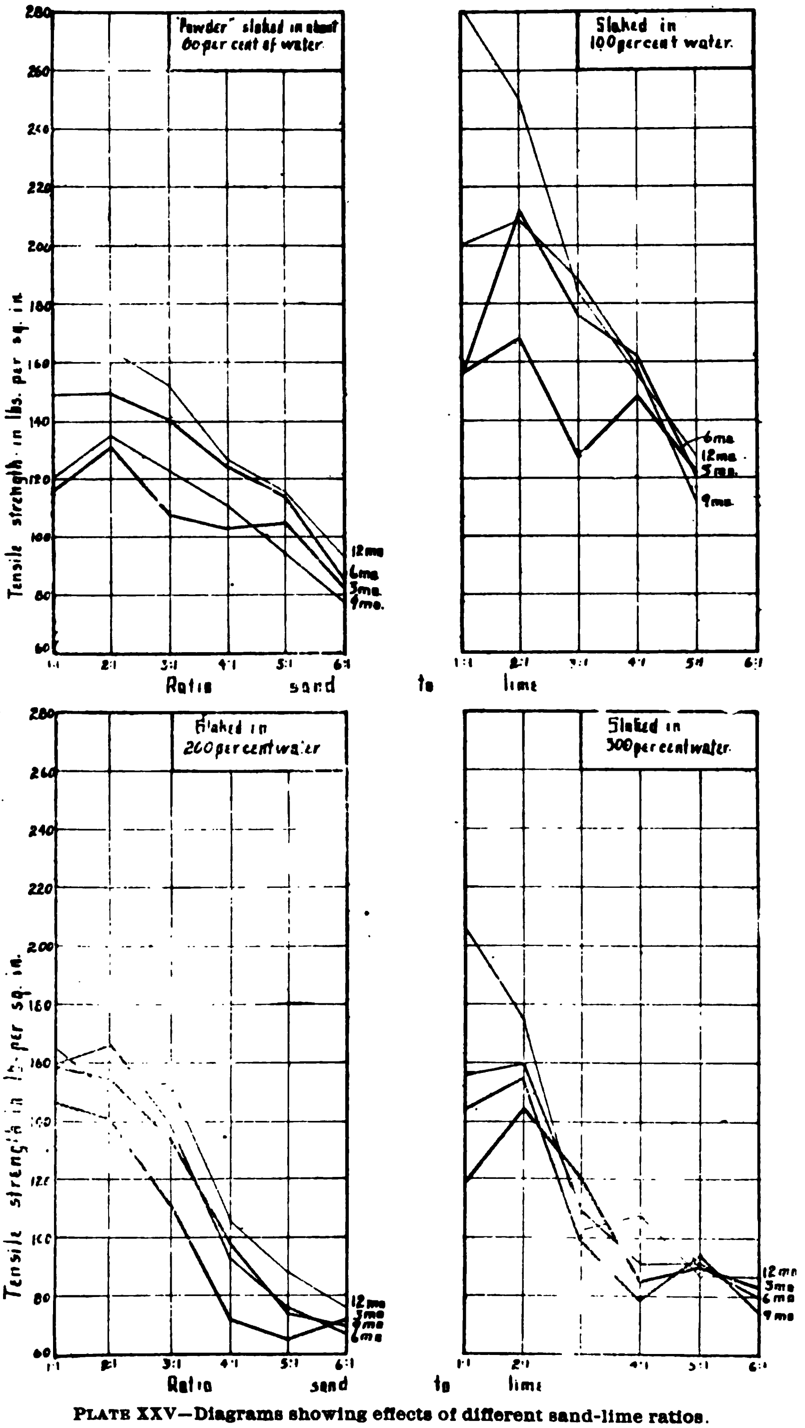

Plate XXV—Diagrams showing effects of different sand-lime ratios.

RESUMÉ.

While the foregoing series of tests are far from exhaustive and serve to open up and suggest many questions that might be profitably investigated, the results obtained are, it is believed, sufficient to base upon them a few generalizations. Some of the statements which follow are of facts that have long been regarded in practice but which have not before been proven by systematic experiment. The limes tested are types of high grade products and may be regarded as representative examples of pure white limes and of the magnesian or dolomitic class. The results, therefore, are to be limited in their general application to these classes and are not to be construed as holding good for the impure or hydraulic limes.

(a) The maximum strength reached within a year's time, is attained at the end of a setting period of six to nine months duration. This is most pronounced where the higher percentages of sand are employed. The notable exceptions to this rule are found with the *lowest* sand-lime ratios, the *lower* percentages of water used to slake, and are most conspicuous in the strongly dolomitic limes.

The cause for the diminution in strength after nine months is not known and results of chemical analyses to determine the amount of carbonation at the end of each of the four periods indicate that this process is in no instance complete at the end of a year's time. Carbonation has progressed to a minor extent only during the first six or even nine months. The change that occurs during the *setting* of the mortar is considered to be largely the crystallization of the lime hydrate. It is possible that such crystallization may produce a bond that is stronger than the carbonate. The process of carbonation displaces the combined water of the hydrate and may as a result actually diminish the cohesive strength of the mortar. If this be true, we would expect such loss in strength to continue till a minimum value is reached, which would either remain constant, or, as the amount of carbonate becomes greater than that of hydrate and carbonation approaches completion, increase again. It is within the range of probability that the ultimate final strength, which might require years for attainment, would be greater than that reached in the first few months of setting. A set of long-time tests, properly designed, should yield valuable information along these lines.

(b) In general, the greatest strength comes with the lower percentages of water used in slaking. Equal amounts by weight of water and of dry quick-lime give in the majority of cases, the highest results. Higher proportions are detrimental to tensile strength. This is more especially noticeable in the white limes.

The generation of a considerable amount of heat, and consequently steam, seems essential in the slaking process, as explained earlier. Too little water leaves hydration, and therefore expansion in bulk, incomplete and the unslaked lime remaining receives its necessary moisture either slowly from the atmosphere or from the water used in mixing for use. The latter slow hydration is not accompanied by the necessary rise in temperature or increase in volume. Too much water prevents the formation of steam and maximum increase in bulk, and therefore retards the slaking. A high excess may keep the temperature so low that combination between water and quick-lime may be evidenced by few if any signs of slaking whatever, for hours after immersion. It would be expected, therefore, that such a percentage of water as would produce the most vigorous slaking action and leave a satisfactory moist paste would afford the best results when tested. This amount varies with different limes as noted in the consideration of each set of results. In every instance, however, the percentage giving the highest strength was that amount which gave the best slake and produced the most workable paste.

(c) As a rule, the highest strength is given by the lowest proportions of sand, the curves being about equally divided between equal parts by weight of sand and dry quick-lime and two of sand to one of lime.

Economy in the use of lime demands that as little as possible be used over that required to fill the voids and to coat each grain of sand with a thin film. The sand particles should be in practical contact with each other throughout. The percentage of pore space in the standard sand used in these tests is essentially 40 per cent. (It will be recalled that this sand is a clean, rounded river sand and represents an average grade and quality such as is obtainable along the streams of Iowa.) Theoretically, therefore, a volume of slaked lime equal to 40 per cent of the total space enclosed by the sand is required to fill the open pores among the grains. If the lime could be confined to the pore spaces alone, still permitting the sand particles to touch at all possible points, such an amount of lime could be added without increasing the apparent volume of the sand, but this is not practically possible.

As noted on an earlier page (page 103), white lime hydrates range in specific gravity from 2.12 to 2.32, and the magnesian averages 2.45. Assume an average for white limes of 2.22 and 2.65 for quartz sand. To be equal in volume to the voids in the sand there would be required in round numbers by weight 36 per cent of the dry lime hydrate. That is, with each sixty-four pounds of sand should be mixed thirty-six of slaked lime (estimated dry) to just fill the space among the grains. There would be required of the average dolomitic lime about thirty-nine in each one hundred pounds of mixture to eliminate the voids in such a standard sand. A liberal allowance would be 40 per cent by weight in each case.

The results of the tests show the highest strength with a 1:1 or 50 per cent mixture. As lower ratios of lime and sand were not employed, it is impossible to do other than speculate on the possible results from such mixtures. It seems probable that mixtures as low in lime as theoretically required to fill the voids may show higher strengths than the lowest proportion used in the foregoing tests. This limit of the series could profitably be extended to include even the neat lime so as to make the results conclusive. As the lime paste is ordinarily used in practice, it contains from 50 to 65 per cent of free moisture, the white limes carrying the larger amounts. In order to make calculations on the dry basis in mixing with sand, it is necessary to evaporate the water from a small sample of the paste, weighing before and after to determine its percentage. Practically, also, sands as they come from the bank contain a considerable percentage of fine material which decreases the voids. River sands range in the neighborhood of 35 per cent. The amount of voids can likewise be determined as directed in an earlier portion of this chapter.

(d) The white limes require more water to slake properly, generate more heat in slaking, slake much more rapidly and reduce to a more uniform paste than the magnesian limes. The dolomitic limes set and harden more slowly but in many cases attain strengths so much greater than do the white limes as to be almost out of comparison. They will, therefore, stand greater dilutions of sand and still be sufficiently strong to meet the requirements of practical use.

Selection of Power Plants and Equipment for Stone Quarries in Iowa.

BY

G. W. BISSELL

SELECTION OF POWER PLANTS AND EQUIPMENT FOR STONE QUARRIES IN IOWA.

G. W. BISSELL.

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CHAPTER III.

*SELECTION OF POWER PLANT AND EQUIPMENT FOR STONE QUARRIES IN IOWA.

It is the purpose of this report to discuss the principles governing the selection and installation of the engine and boiler plants which furnish the power required for quarrying and crushing stone, as practiced generally in Iowa quarries.

The writer has assumed that in the selection of the power producing apparatus the following requirements exist: All machinery must be (1) simple in design, (2) strong in construction, (3) reliable in action, (4) reasonable in first cost, and (5) readily handled by men of ordinary intelligence and some mechanical aptitude.

Economy of operation should also receive some attention but since the operation of the plant is limited to the open season, economy is not of as much importance as the other requirements first named.

The Power House.

The building in which the engines and boilers and accessories are placed need not be elaborate or expensive, but should be so constructed as to protect the machinery and its attendants from the weather while the plant is in use, should protect the machinery from meddling persons and the weather while the plant is not in use and should be so located, and the machinery so arranged therein, that the capacity of the plant can be increased by adding to the existing building. Plenty of light and controllable ventilation are very desirable in the power house. If the quarry is large and likely to be worked for several seasons, it will pay to put up a substantial power house. The use of stone, as

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*See also Iowa Geological Survey. Vol. XIV, p. 349.

masonry or concrete, naturally suggests itself and a good roof, doors and windows to be shuttered and barred during the winter should be included.

Machinery.

This consists usually of engines, boilers and stacks, and feed-pumps or injectors. For most localities feed water purifiers should be added to the list. If crushing is not a part of the business, the boiler, which furnishes steam to the drill, is the principal item of equipment. Undoubtedly future practice will develop the use of the gas or gasoline engine for driving the crusher and air-compressor for drilling.

BOILERS.

The most satisfactory all around boiler is the well known horizontal return tubular boiler shown without the brick work and castings in Fig. 1, and plate XXVI. Fig. 1 represents a boiler adapted to suspension, to which reference is made below. For Iowa coal as fuel the boiler should have relatively long tubes,

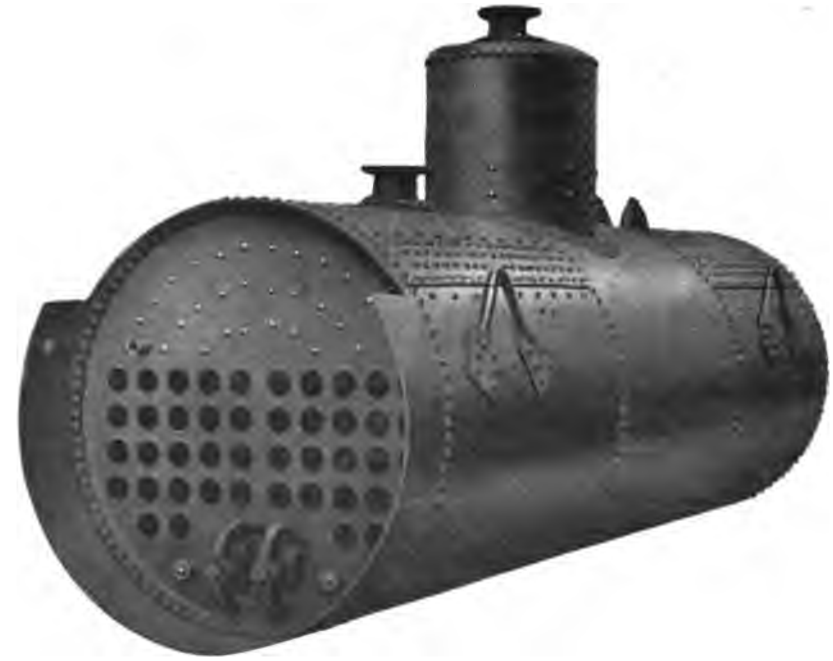


FIG. 1—Boiler with dome, shell extended for full front, wrought iron hinges.

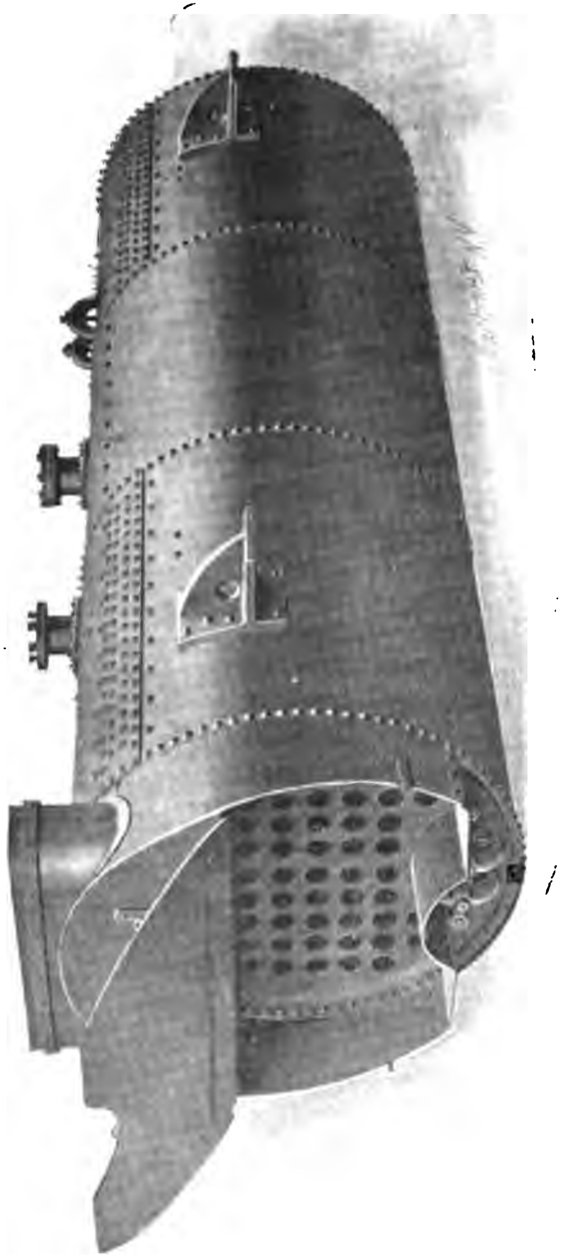


PLATE XXVI—Domeless boiler with nozzles, shell extended and fitted with flue door and up-take for half arch front, manhole exposed, cast iron lugs. Can be suspended.

should be set high above the grates, should have liberal grate surface and be connected to a stack of ample capacity.

Tubes four inches in diameter should be eighteen feet long and three and one-half inch tubes should be sixteen feet long. Tubes smaller than four inches are not advisable for natural draft with Iowa coals, on account of the excessive soot accumulation in smaller tubes.

The grate surface should be liberal so as to permit the use of slack or the carrying of a heavy enough fire of any grade of Iowa coal to compel a thorough mixture of the air and combustible gases of the fuel.

Twelve square feet of water heating surface per boiler horse power, and one square foot of grate surface to each forty square feet of heating surface will be found satisfactory. Rocking and dumping grates are very desirable.

Automatic stokers are not practicable in plants for quarries in Iowa. Most boiler shells are too near the fire for the economical use of Iowa coal. A seventy-two-inch boiler should be not less than thirty-six inches above the grate. The following table contains approved dimensions for boilers of this type for shells from forty-eight inches to seventy-two inches in diameter, and from sixteen feet to eighteen feet in length, with four-inch tubes:

TABLE GIVING DIMENSIONS FOR BOILERS.

Diameter of boiler		48 in.	54 in.	60 in.	66 in.	72 in.
Number of tubes		24	36	44	54	68
Diameter of tubes		4 in.	4 in.	4 in.	4 in.	4 in.
Thickness of shell		5/16 in.	5/16 in.	5/16 in.	3/8 in.	3/8 in.
Thickness of head		7/16 in.	1/2 in.	1/2 in.	1/2 in.	9/16 in.
Braces above tubes		12	20	30	30	40
Braces below tubes		4	4	4	4	8
Size of steam pipe		3½ in.	4 in.	4½ in.	5 in.	6 in.
Size of feed pipe		1¼ in.	1¼ in.	1½ in.	1½ in.	1½ in.
Size of blow-off pipe		2 in.	2 in.	2 in.	2½ in.	2½ in.
Heating surface	16 feet	sq. feet 520	sq. feet 715	sq. feet 864	sq. feet 1042	sq. feet 1325
	18 feet	sq. feet 585	sq. feet 805	sq. feet 972	sq. feet 1270	sq. feet 1490
Rated horse power	16 feet	43.3	59.5	72	87	110
	18 feet	48.7	67	81	90	124
Grate surface	16 feet	sq. feet 14	sq. feet 18	sq. feet 21.6	sq. feet 30	sq. feet 33
	18 feet	sq. feet 15.8	sq. feet 22	sq. feet 24.3	sq. feet 33	sq. feet 39.6
Diameter of 60-foot stack		24 in.	27 in.	30 in.	33 in.	36 in.

Herewith is a standard "Specification" for boilers of the same type, based upon the practice recommended by the Hartford Steam Boiler Inspection and Insurance Company.

SPECIFICATIONS FOR HORIZONTAL RETURN TUBULAR BOILER, 72 INCHES BY 18 FEET.

WORKING PRESSURE, 125 POUNDS.

Type.—Horizontal return tubular.

Dimensions.—Seventy-two inches in diameter, eighteen feet long from outside to outside of heads, with smoke extensions eighteen inches long continuous with shell. Thickness of shell, three-eighths inch, of head, one-half inch.

Material.—Best open hearth flange steel, having a tensile strength of not less than 57,000 nor more than 62,000 pounds, and deductility corresponding to 56 per cent reduction of area and 25 per cent of longation. All plates in finished boiler to show stamp with name of maker, quality and tensile strength.

Riveting.—Triple riveted butt-joints for longitudinal seams and single riveted lap joints for girth seams.

Tubes and Braces.—Sixty-eight tubes, four (4) inches in diameter, eighteen feet long, best lap welded or seamless drawn, carefully and properly expanded with Dudgeon expander and beaded at each end. Braces: Forty braces above tubes and four below tubes, the former crow foot form, flat or round, of not less than one square inch in area at smallest section, the latter 1¼ inches in diameter, with up-set ends for 1½ inch thread at front and crow-foot connections at back, with turned bolt 1 1-16 inch diameter. No brace less than 3 feet 6 inches long.

Details of tube sheet lay-out to be according to practice recommended by the Hartford Steam Boiler Inspection and Insurance Company.

Supports.—Two lugs on each side. Front lugs to rest on cast iron plates, others on rollers and plates to permit of expansion. All plates 12 by 12 by 1½ inches. Rollers 1 inch diameter, 9 inches long, three at each plate. Or two suspension loops on each side, of 1½ inch round iron securely riveted to shell. Columns and double channels for overhead suspension, with equalizing I-beam at back end. See plate XXVII.

Construction.—No dome. Shell in three rings, each ring formed from a single sheet, horizontal seams above the fire and to break joints. Heads machine flanged, rivet holes drilled or punched and reamed, tube holes drilled or bored.

Openings.—Two man-holes, 11 by 15 inches in top of shell, 10 by 15 inches in front head, under tubes. One and one-half inch feed-water pipe, internal from front head over tubes. Blow-off flange 2½ inches. Steam nozzle 5 inches, near back end, safety valve nozzle 4 inches, near front end. Both nozzles flanged and fitted with companion flanges for screwed pipes of same size as nozzles.

Castings.—Fronts. Ornamental three-quarter arch for overhanging extension. Fronts designed to allow not less than 42 inches between grate and boiler shell and to have fire-door frames for 8-inch wall. Tight fitting fire, ash-pit and smoke extension doors, saddle for breaching connection with balanced butterfly damper. Eight wall binders, binder rods, anchor rods for front, soot door and skeleton frames for fire brick arch at back. Uptake 14 by 60 inches. Rocking dumping grates of approved design to work from front of boiler.

Fittings.—Eight-inch brass steam gauge, combination water column, 4-inch pop safety valve, 1½-inch check and stop valves and 2½-inch asbestos blow-off cock.

Inspection and Test.—Before shipment test with cold water at 175 pounds per square inch and furnish certificate of inspection from the Hartford Steam Boiler Inspection and Insurance Company, and insurance policy in the same company for one year.

ALTERNATE SPECIFICATIONS FOR BOILER 66 INCHES BY 18 FEET.

Complying with specifications for the 72-inch boiler, except as follows:

Diameter, 66 inches. Length, outside to outside, 18 feet.

Thickness of shell, ⅜-inch. Riveting, double riveted lap for longitudinal seams.

Fifty-four tubes, 4 inches by 18 feet.

Braces above tubes, 34.

Braces below tubes, 4.

Uptake, 12 by 54 inches.

Steam pipe, 4½-inch. Safety valve, 3½-inch.

Blow-off, 2-inch.

Feed pipe, 1½-inch.

ALTERNATE SPECIFICATIONS FOR BOILER 60 INCHES BY 18 FEET.

Complying with the specifications for the 72-inch boiler, except as follows:

Diameter, 60 inches. Length, outside to outside, 18 feet.

Thickness of shell, 5-16 inch. Riveting, double riveted lap for longitudinal seams.

Forty-four tubes, 4 inches by 18 feet.

Braces above tubes, 30.

Braces below tubes, 4.

Uptake, 12 by 42 inches.

Steam pipe, 4-inch. Safety valve, 3½-inch.

Blow-off, 2-inch.

Feed pipe, 1¼-inch.

Complete specifications and setting plans for any size of horizontal return tubular boiler can be had by applying to the Hartford Steam Boiler Inspection and Insurance Company. In the judgment of the writer, they should be modified along the lines suggested in the above specifications.

The capacity of the stack depends upon its cross-sectional area, its height, the temperature inside and outside and general atmospheric conditions.

The table given below, adapted from a more complete table in Snow's "Steam Boiler Practice," p. 236, gives the capacities in horse power of chimneys or stacks of various heights and diameters for ordinary conditions as to temperature of the hot gases and for average atmospheric conditions.

TABLE SHOWING CAPACITIES IN HORSE-POWER OF CHIMNEYS.

Inside diameter, inches	Effective area, square feet	Height of Chimney in Feet				
		60	80	100	125	150
18	0.97	25	29	....	....	....
24	2.08	54	62	....	....	....
30	3.58	92	107	119	....	....
36	5.47	141	163	182	204	....
42	7.76	....	231	258	289	316
48	10.44	....	....	348	389	426
54	13.51	....	....	449	503	551
60	16.98	....	....	565	632	692
84	34.76	....	....	....	1294	1418

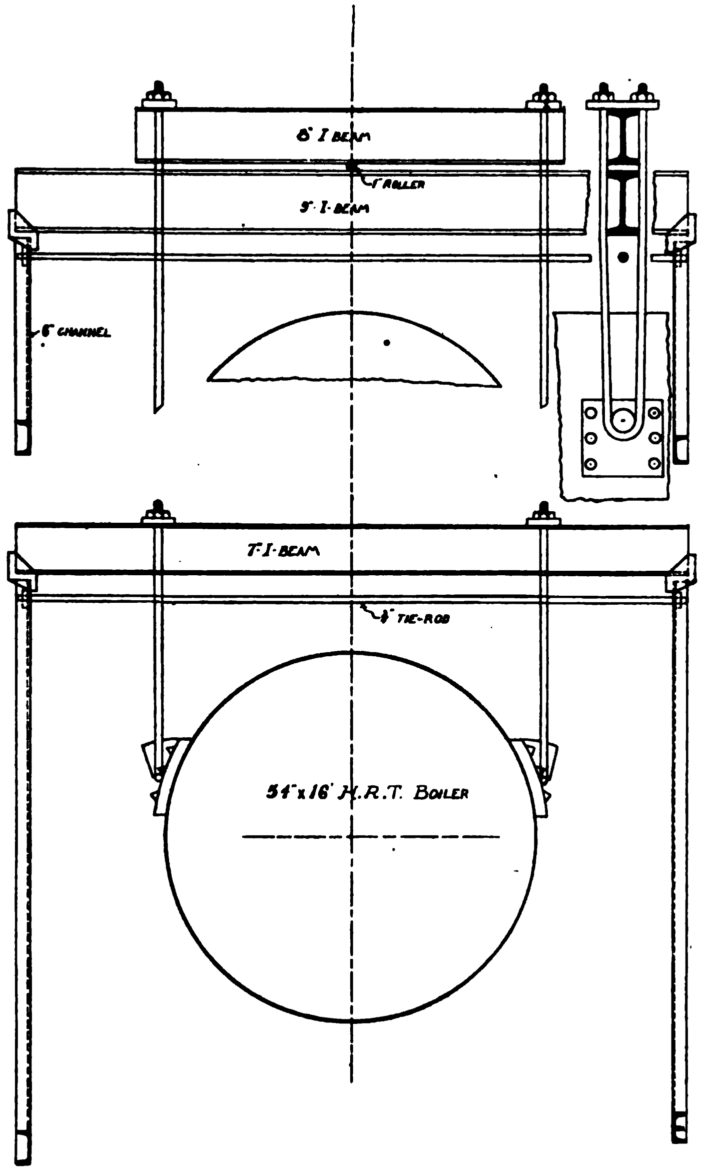


PLATE XXVII—Method of hanging a shell boiler.

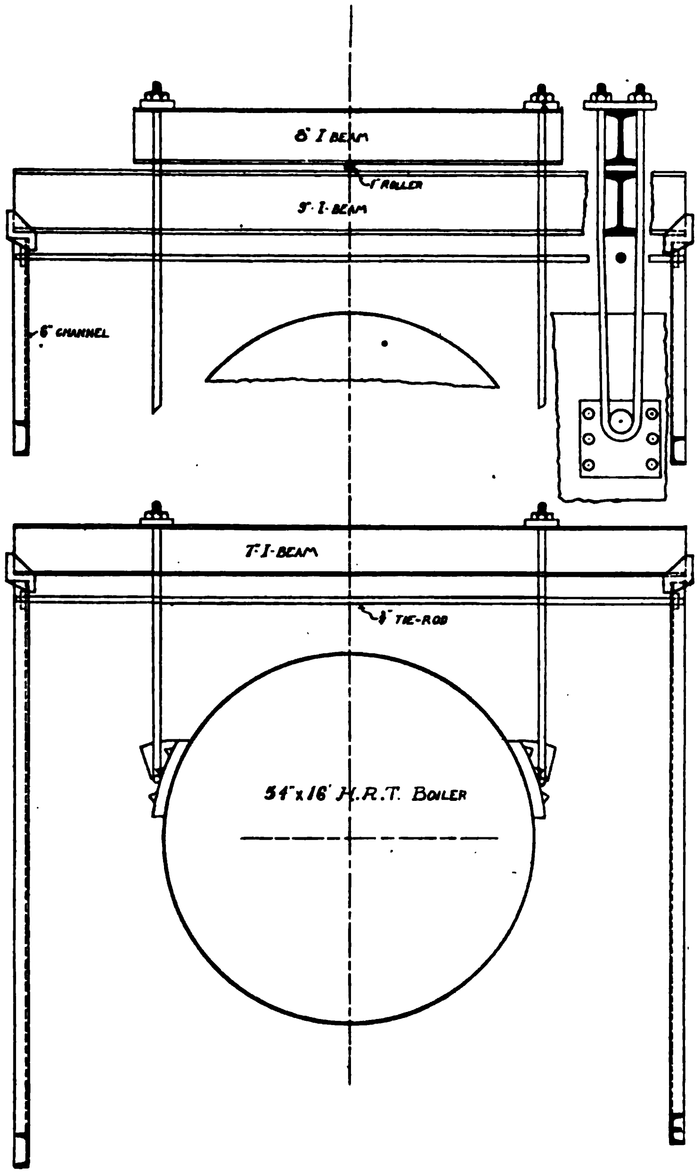


PLATE XXVII—Method of hanging a shell boiler.

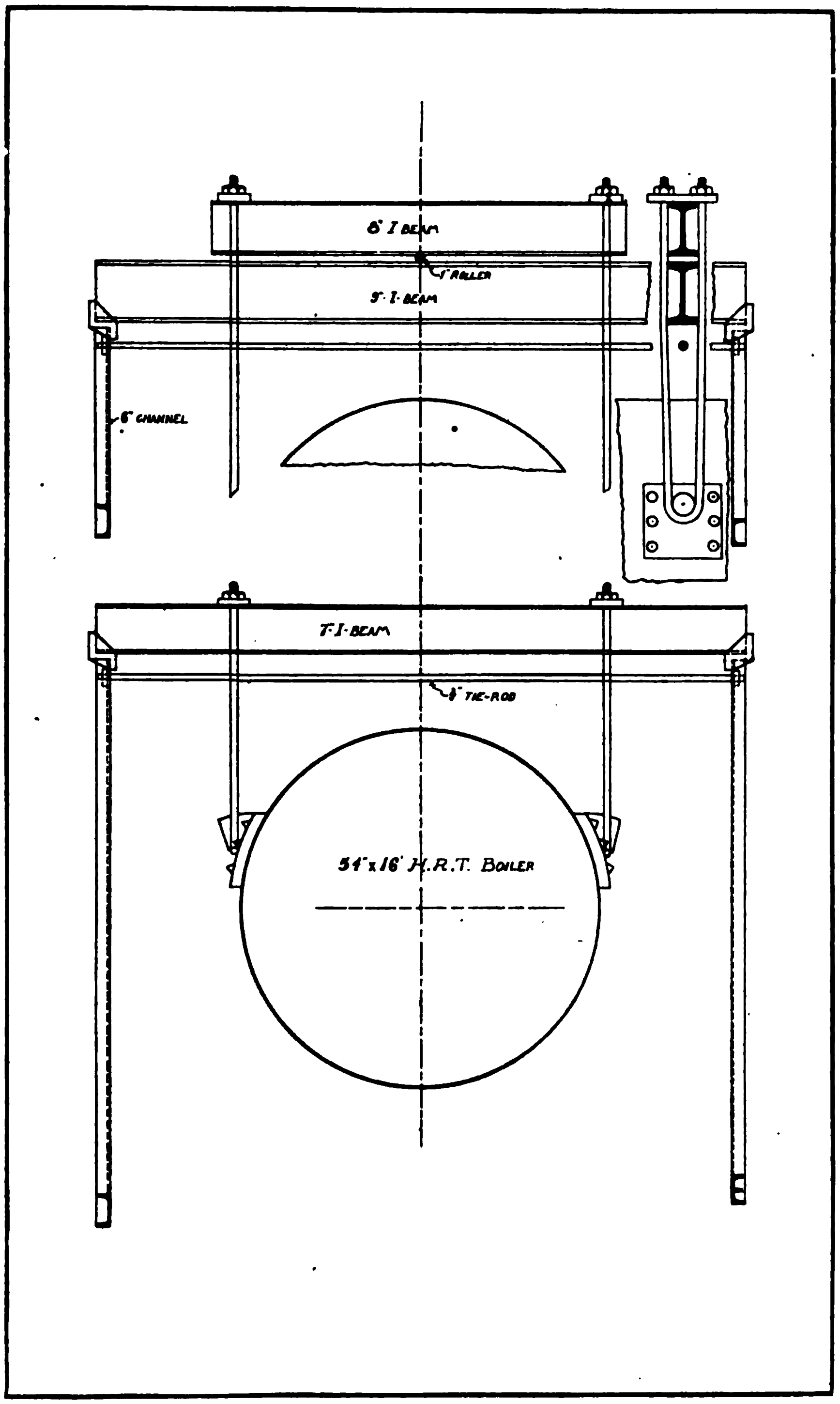
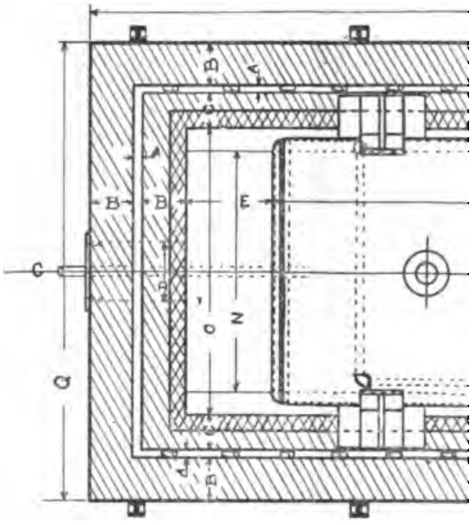


PLATE XXVII—Method of hanging a shell boiler.

Setting for One 72 Inch Horizontal Tubular Boiler.

▨ Common Brick.

▨ Fire Brick.



Horizontal

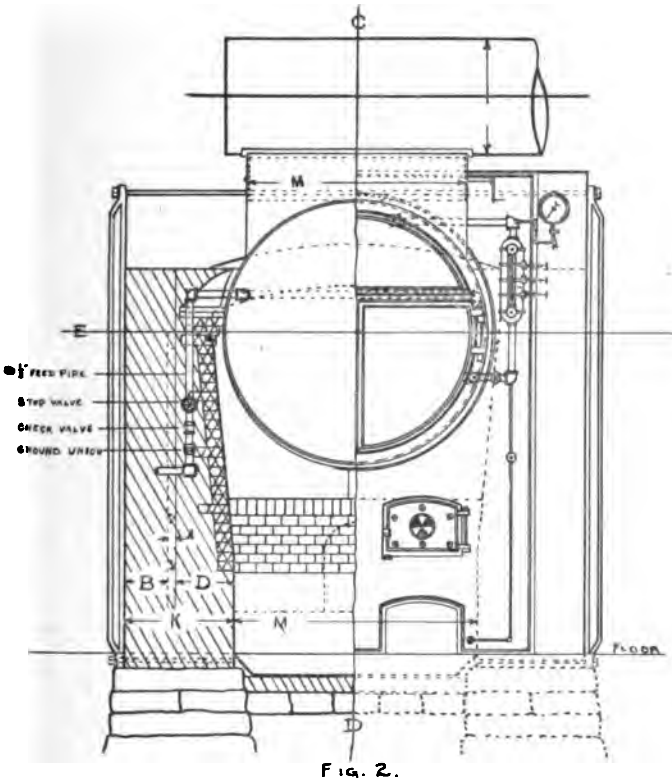
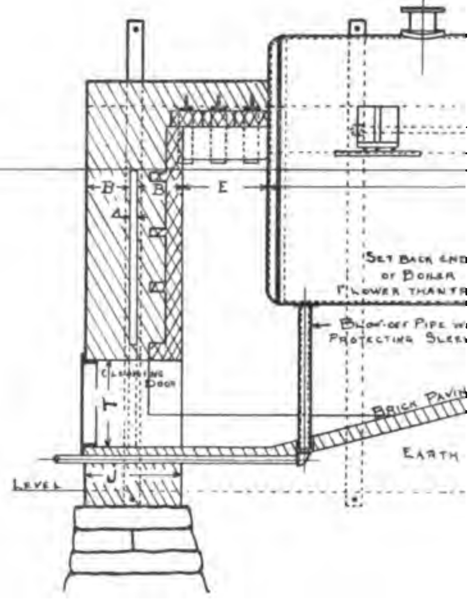


Fig. 2.

Transverse Section of Walls at "A-B" Figs. 1 & 3.

Front Elevation


Level
B
B
E
4
Set back end of Boiler 1" lower than fr
Blow-off Pipe wi Protecting Sleev
Cleaning Door
T
J
Brick Pavin
Earth

Longitudi

A substantial brick stack is better than an unlined steel stack such as is commonly furnished with boilers, but a self supporting steel stack lined to the top with brick is considered good and costs somewhat less than an all-brick stack.

For Iowa feed-water the boiler should be made as accessible as possible for interior examination and cleaning. To this end a man-hole below as well as above the tubes is a necessity.

A dome is not desirable, and its cost can be saved by omitting it from the specifications.

The feed-water should be introduced at the front and above the tubes, below the water line, through a pipe extending to within two feet of the back head, and discharged downwards between the tubes and the shell.

The boiler should preferably be hung on columns by means of equalizing levers and hangers, so as to keep the shell free from strains due to settling of the brick work.

A method of hanging a shell boiler which can be applied to a boiler of any size is shown in plate XXVII as designed by the writer for a 54-inch boiler, 16 feet long.

Plate XXVIII shows the standard setting plans for a 72-inch by 18-foot boiler. For other sizes the thickness of walls would be the same, but the general dimensions would conform to the size of the boiler shell. The overhanging front shown is better than the flush front. Two lugs on each side would be better than three, as shown.

Size of Boiler.—The boiler must be large enough to drive the engine and the drills. The information needed must be obtained from the builders of the machines and a margin allowed for poor coal or fireman or both. It is impossible to state a general rule for determining the size of the boiler except twelve square feet of water heating surface equals one horse-power of boiler capacity for this class of work.

BOILER FEEDING.

The most reliable boiler feeder is a direct acting single or duplex pump as illustrated in Figures 2 and 3 and plate XXIX. The exhaust therefrom can be used to help in the heating of the feed-water as explained later. A second pump, or an injector, should be installed in reserve.

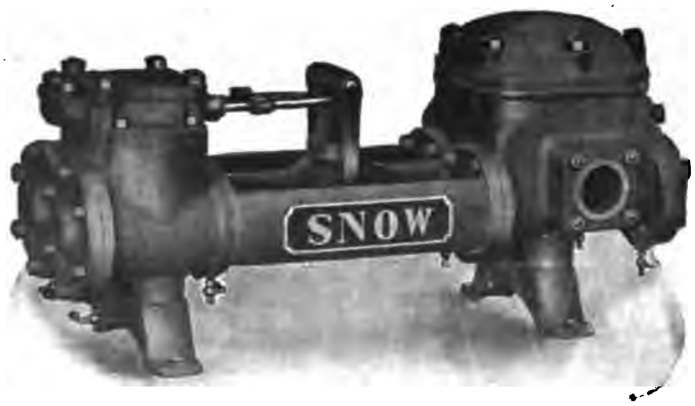


Fig. 2—Type of boiler feed-pump, duplex.

The use of cold feed-water, where it can be heated by otherwise waste heat, is uneconomical. It is perfectly practicable by means of exhaust steam from the auxiliary engines (pumps), or the main engine, to heat the feed-water to 200 degrees F., or even 210 degrees F. This will effect a saving of 10 per cent or more in the fuel consumed by the boiler.

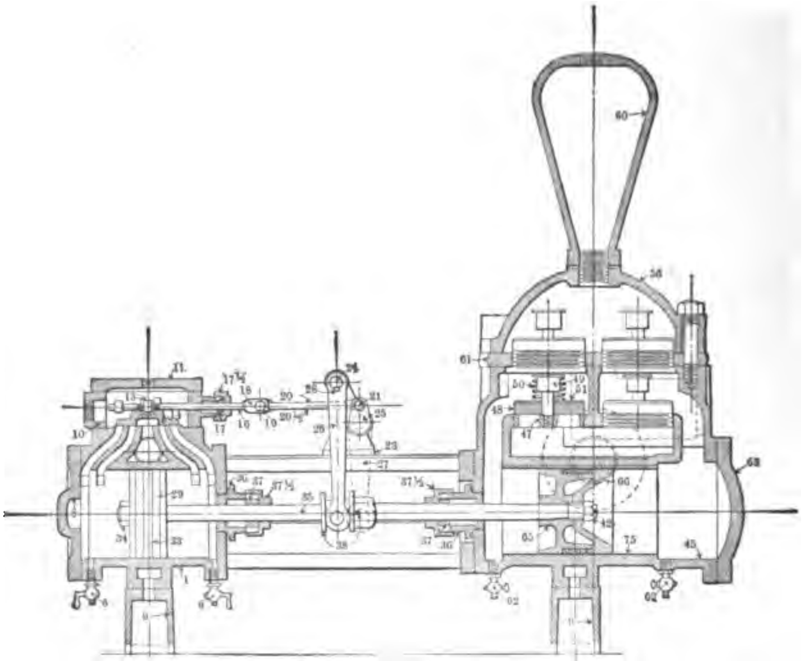


Fig. 3—Duplex pump in section.

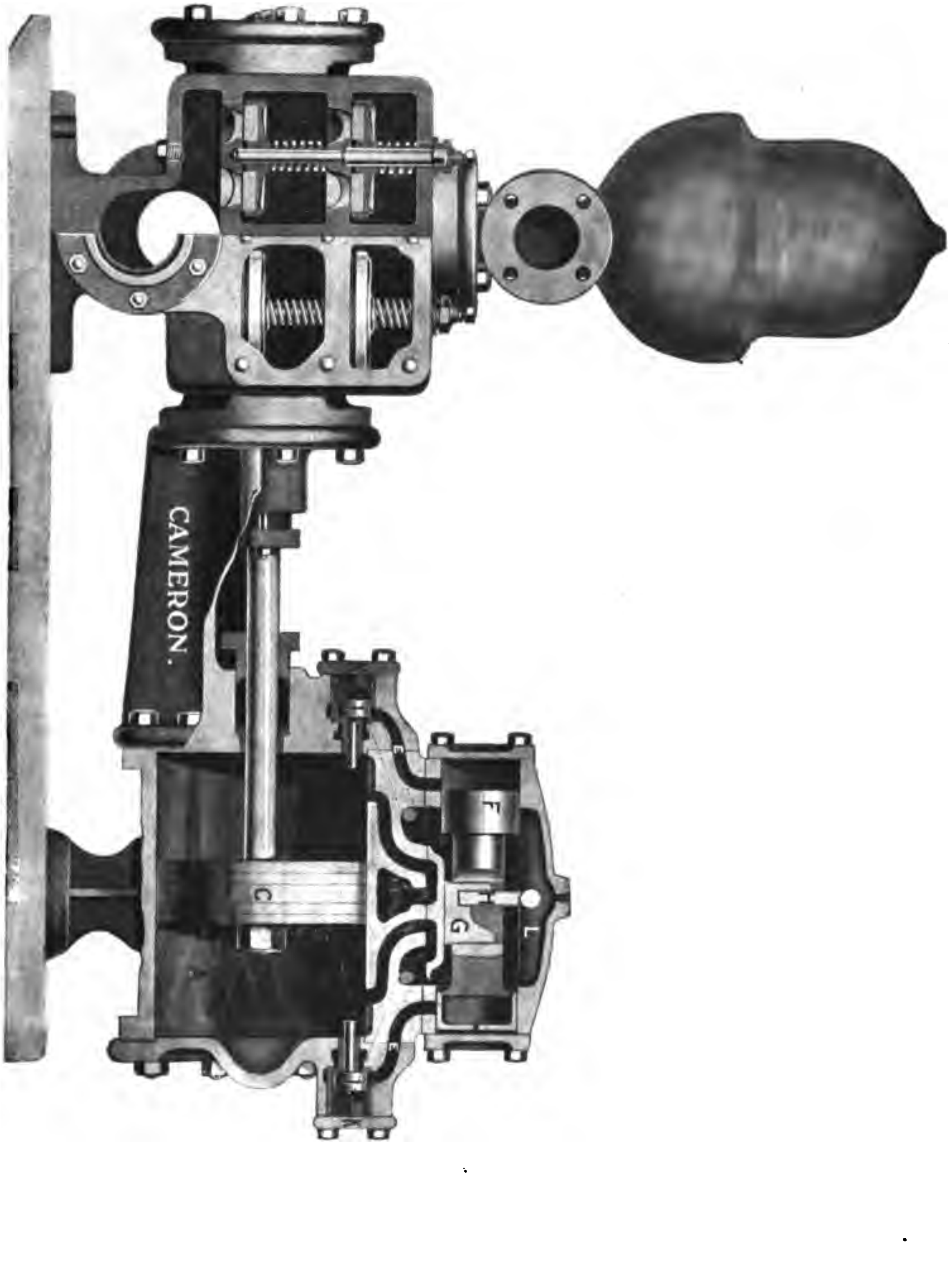


PLATE XXIX—Type of boiler feed-pump; simple direct acting, in section.

The use of cold feed-water is also bad for the boiler, because of sudden strains thrown upon the shell plates and seams, which lessen the life of the boiler.

Feed-water heaters can be built so that they will act as purifiers, thus counteracting in a measure, the "hardness" of the feed-water.

The cost of a heater and purifier is insignificant compared with the saving effected by its installation and use.

When waste heat is applied to the feed-water the saving which may be effected is given by the following table:

TABLE GIVING PERCENTAGE OF FUEL SAVED BY HEATING FEED-WATER.

(Steam Pressure, 80 Pounds.)

Initial Temperature of Water	Temperature of Water Entering Boiler—Degrees F.								
	160°	180°	200°	202°	204°	206°	208°	210°	212°
40° F...	10.23	11.93	13.64	13.81	13.87	14.15	14.32	14.49	14.66
50° F...	9.46	11.18	12.90	13.07	13.24	13.41	14.58	13.75	13.92
60° F...	8.67	10.40	12.13	12.31	12.48	12.65	12.83	13.00	13.17
70° F...	7.87	9.62	11.37	11.54	11.72	11.89	12.06	12.24	12.41
80° F...	7.08	8.85	10.61	10.78	10.95	11.12	11.29	11.46	11.63

There are many forms of exhaust feed-water heaters on the market. They may be classified as open heaters and closed heaters.

Fig. 4 shows in diagram the essential features of the open heater and Fig. 5 those of the closed heater.

Two principal differences are noted. In the open heater the steam and the feed-water are in contact and the feed-water is not under pressure. In the closed heater the steam and the feed-water are under pressure.

In general there are claimed for the open heater the following principal advantages:

1. The open heater is essentially more efficient than the closed heater, because the steam which furnishes the heat comes into intimate contact with the water to be heated, and the resulting temperature of the latter is higher than can be in the case of the closed heater, wherein all heat transfer must be effected through metal partitions which offer some resistance

to such transfer. With water free from scale-forming solids and from grease, this resistance is practically negligible where the metal partitions are of clean copper, but in the majority of cases the feed-water is far from pure and the conductivity of the metal partitions is seriously impaired by scale and grease.

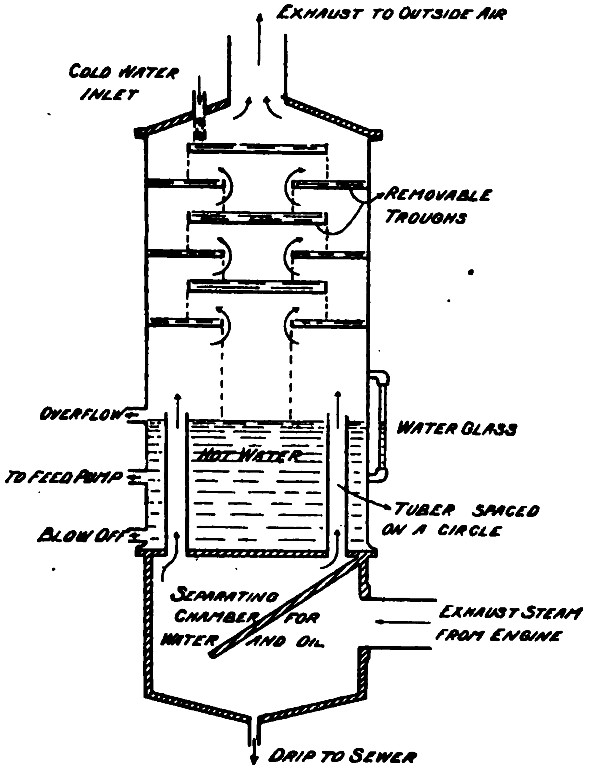


FIG 4—Open feed-water heater.

2. The open heater, as usually constructed (See Fig. 4), is provided with pans, trays or troughs over which the feed-water passes at a low velocity, depositing thereon much of the scale-forming matter; in fact, a portion of the scale is deposited in the heater instead of in the boiler. This partial purification is effected without impairing the efficiency of the heater. In the closed heater the deposition of the scale on the metal partition is objectionable as above stated.

3. If, for any reason, the exhaust steam of the main engine is otherwise utilized, the exhaust steam from the feed pump and other auxiliaries can be used in either style of heater. In either case most or all of it will be condensed by the feed-water. In the open heater this results in a direct saving in the amount of water required for the plant.

4. In the open heater the air in the feed-water is largely liberated by the heat and passes off with the exhaust steam. In general the closed heater should be used if the water is very free from mineral impurities or contains only those impurities which will not precipitate at the temperatures attainable with exhaust feed-water heaters.

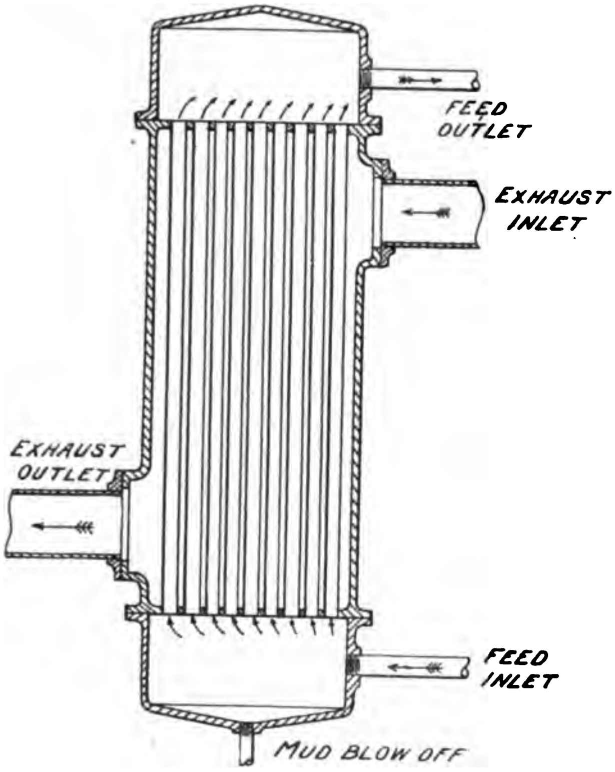


FIG. 6.

FIG. 5—Closed feed-water heater.

If the closed heater is used it should be placed in the main exhaust pipe and the feed-water may be handled with an injector arranged to deliver to the boiler through the heater, thus saving the difference in cost between a pump and an injector. All things taken into account, the open heater will best meet the needs of the plants under consideration.

In selecting an open heater the following features should be required:

1. A separator, either as an integral part of the heater itself, as indicated in Fig. 4, or as a separate appliance in the main exhaust pipe, or in each of the exhaust pipes of all engines discharging their exhaust through the heater. The former design is preferred.
2. A reservoir or receiver for the heated water, so designed that the water is kept hot until withdrawn by the pump. One way of constructing such a reservoir is shown in Fig. 4. The exhaust steam passes through a number of tubes surrounded by the feed-water.
3. The reservoir should be capacious and provided with blow-off, overflow and water glass. The feed pump connection should be a few inches above the blow-off.
4. A large heating and purifying chamber containing pans, trays or troughs so arranged that the cold feed-water shall flow over all of them in order that the exhaust steam shall be compelled to come in contact with the water on every tray.
5. The trays should be readily removable and of such construction that the accumulation of scale thereon can be knocked off or picked off without injury to the trays.

It is a good plan to extract the grease from the exhaust steam used for heating the feed-water, because most cylinder oils are injurious to a boiler when allowed to accumulate therein.

FIRING.

A bad fireman is a poor investment, even if he pay for the privilege of firing, and a good fireman is a jewel. In spite of the extensive use of automatic stokers in large plants, it remains a fact that intelligent hand firing is more economical than machine firing for most plants. The secret of good firing is in securing the right amount of air at all points in the fire. The top of the stack is a good indicator of the economy of the fire box, and a window in the roof of the boiler room, with a man under it who will look up, are useful adjuncts to any boiler room.

For the proper handling of his fuel the fireman should have knowledge of its properties. For the information of users of Iowa coal the following discussion will be found of value: Iowa coals are almost entirely bituminous and non-coking. "In nearly all cases ordinary breakage of coal yields more or less of cubical blocks of varying size" which are much broken up by transportation and weathering. The amount of breakage depends also upon whether the "long wall" or "shooting" method of mining is used. In the former the coal is undermined and broken off by settling of the roof or wedged down, and in the latter the coal is removed by drilling and blasting. The latter process breaks up the coal very thoroughly and is a quicker process, but lessens the value of the product.

An average of 64 analyses by the State Geologist gives the following chemical composition:

*Moisture	8.57
Fixed carbon	45.42
Volatile matter	39.24
Ash	6.77
	100.00

Analyses of coal from 16 mines in the Des Moines River district give:

**Moisture	8.08
Fixed carbon	45.60
Volatile matter	38.14
Ash	8.18
	100.00
Sulphur	3.42

or on the basis of oven dried samples,

**Fixed carbon	49.62
Volatile matter	41.49
Ash	8.89
	100.00
Sulphur	3.72

---

* Steam Boiler Economy, Kent, page 74.
** F. M. Weakly, The Iowa Engineer, June, 1902.

In 1901-02, at the Iowa State College, Mr. F. M. Weakly made a study of the chemical compositions of Iowa coals, from which the following is quoted:

"The moisture in Iowa coals varies (for the coals tested) from 4.03 to 17.47, the average being 8.08. This moisture is high, as compared with that in coals of other states.

"Eliminating moisture from our comparisons, in volatile matter the Iowa coals are rich, varying from 36.94 to 48.69, with an average of 41.49.

"The fixed carbon ranges from 44.86 to 54.91, with an average of 49.62, slightly lower than that of many coals from other states.

"Total combustibles are high, running from 84.88 to 95.91, with an average of 91.11.

"Ash is low, being from 4.09 to 15.12, with an average of 8.89.

"Sulphur is high, from 2.27 to 7.41, with an average of 3.72.

"The coals high in sulphur are also high in ash."

Concurrently with the work of Mr. Weakly, Messrs. Austin and Peshak, under the direction of the writer, determined the calorific powers of samples of coal from twenty or more mines from the same district, fourteen of the samples being the same as used by Mr. Weakly.

The following table exhibits the results of the work of Messrs. Austin and Peshak:

CALORIFIC POWER OF IOWA COALS AND OTHER FUELS.

PER POUND OF DRY FUEL.

	B. T. U.
Slack coal, Marquisville, Iowa	10574
Spring Valley, Ill	12608
West Virginia screenings	11361
Lumsden Coal and Mining Company	12097
Des Moines Coal and Mining Company	12041
Whitebreast Fuel Company, Hilton, Iowa	12396
Whitebreast Fuel Company, Pekay, Iowa	13050
Hocking Valley Coal Company, Mine No. 1	12037
Hocking Valley Coal Company, Mine No. 2	12560
Lumsden Coal Company, Bloomfield, Iowa	13204
Kalo, Iowa	10451
Centerville Block Coal Company	12681
Eldon Coal and Mining Company, Laddsdale	13141

Consolidated Coal Company, Buxton, No. 10	12030
Consolidated Coal Company, Buxton, No. 11	10585
Lodwick Brothers Coal Company, Mystic	12780
Carbon Coal Company, Willard	12245
Crcwe Coal Mining Company, Boone	12729
Corey Coal Company, Lehigh	12431
Platt Pressed and Fire Brick Company, Van Meter	11941
Jasper County Coal and Mining Company, Colfax	12134
Empire Coal Company	10881
A. A. Conway Coal Company	10132
Anthracite coal	12532
Crude petroleum, Beaumont, Texas	19000
Crude petroleum, Chanute, Kansas	19488
Lamp black	14467

CALORIMETER TESTS.

In the subjoined table are presented the heating values and in some cases other information obtained from samples of Iowa coal gathered from boiler rooms and car lots as delivered to consumers. The Parr Standard Coal Calorimeter was used in the calorimetric determinations.

Designation	County	Grade	B. T. U. per lb. Dry Coal	Proximate Analysis				
				Carbon		Ash	Moisture	Sulphur
				Volatile	Fixed			
Smoky Hollow		Steam	9719	35.4	37.8	16.0	10.8	
Anchor		Steam	9963	33.0	41.7	15.3	10.0	
Anchor		Lump	11027	30.7	45.0	16.0	8.2	5.03
Roseland		Steam	8594	30.7	41.2	15.7	11.2	
Avery		Steam	9655	34.4	39.5	15.0	11.0	
Colfax	Jasper	Steam	10742	30.8	41.5	16.2	11.5	
Flint Brick	Polk	Steam	9952	30.1	39.5	16.2	13.0	
Norwoodville	Polk	Steam	10479	32.3	38.4	15.0	14.2	
Mammoth Vein	Marion	Lump	10019	33.1	37.4	15.2	14.2	4.66
Gibson Coal Mining Co	Polk	Lump	10244	36.9	35.1	14.0	13.8	6.15
Centerville Blk	Appanoose	Lump	10723	35.5	39.3	10.9	14.0	4.26
Inland Fuel Co	Lucas	Lump	10242	30.4	41.4	12.6	15.3	3.19
*Johnson, 9	Boone	Slack	7363	22.1	26.1	40.1	11.7	
Johnson, 5	Boone	Lump	11412	27.7	41.6	15.2	15.3	
Rogers, 3	Boone	Slack	7463	20.4	26.1	41.2	12.0	
Heaps & Crowe, 1	Boone	Lump	9905	27.8	32.9	26.0	13.3	
Heaps & Crowe, 4	Boone	Slack	7588	14.8	31.2	42.0	12.0	
Marquisville	Polk	Nut	11136	30.0	43.5	20.6	5.8	

*The number of cars of each kind from which samples were obtained is indicated by the numerals.

In 1900 boiler tests at the Iowa State College gave the results exhibited in the table below:

TABLE SHOWING COST OF FUEL AND OF STEAM.

Kind of Fuel	Cost per Ton of 2,000 lbs.	Fuel Cost of 1,000 lbs. Steam at 212°
Marquisville slack	$1.43	14.9 cents
Marquisville steam	2.35	21.2 cents
Marquisville nut	2.54	21.5 cents
Marquisville lump	2.28	24.0 cents
Coke, eastern foundry	8.00	60.4 cents
Anthracite nut	8.95	52.8 cents

The interesting features of these results are the prohibitive cost of anthracite and coke and the advantage of slack over the better grades of coal from the same mine.

It is evident that transportation charges will materially change the relative values of coal for steam generation. It is also true that the method of handling, the design of the boiler setting and the character of the fuel itself as to ash, sulphur and moisture will materially influence the cost of generating a unit quantity of steam.

Methods of Firing.—Frequent and small charges of fuel intelligently distributed will enable the burning of the poorest fuel with a minimum of smoke and a maximum of economy even in furnaces which are not ideal in their construction. Slack and steam coal should be fired in thin beds, three to six inches, and lump coal ten to twelve inches, and the fires should not be disturbed too often by shaking or poking.

Wetting the fuel before firing is sometimes useful in promoting coking and preventing the carrying off small particles of unburned coal.

Flues should be frequently cleaned by scraping or blowing with steam or air. A steam jet over the fire is useful when the coal is freshly fired, but is detrimental at other times. If used continuously the loss of heat in the steam is appreciable, and being useless, is inexcusable.

The ideal conditions for combustion exist when the air supply is from one and one-half to two times the theoretical amount and when the same is thoroughly mixed with the combustible portion of the fuel at a temperature equal to or greater than the temperature of ignition. These conditions can be very nearly attained for Iowa coal if the principles of the boiler and the furnace design and operation above enumerated are followed.

ENGINES.

The selection of an engine is not governed by rules so much as by the individual judgment of the purchaser. Consequently, engines vary more in detail than boilers of the type above discussed.

The writer is of the opinion that up to 100 horse power the moderate speed throttling or automatic engine will best meet the needs of quarrymen. For either type the following general proportions should be observed:

Diameter of steam pipe equal to one-third cylinder diameter.

Diameter of exhaust pipe equal to one-half cylinder diameter.

Diameter of piston rod equal to one-sixth cylinder diameter.

Diameter of shaft equal to one-half cylinder diameter.

Diameter of crank pin equal to one-third to one-half cylinder diameter.

Length of connecting rod equal to three times length of stroke.

The effective power of a single cylinder, high or medium speed engine can be calculated by use of the formula:

Horse power = 0.002 x L x A x N wherein
L = length of stroke in feet.
A = area of piston in square inches.
N = number of revolutions per minute.

The engines are supposed to use steam at 125 pounds, boiler pressure. Increase in boiler pressure will give a proportionate increase in capacity of engine in either case.

In addition, it should be remembered that durability is proportional to weight, and that weight is cheap in first cost, that convenience in adjustment, simplicity of detail and perfect lubricating devices are essential.

Engine foundations should be massive and well built. They should rest on hard and natural soil or rock, and the engine should be securely bolted thereto.

Size of Engine.—Double the power required to drive the crusher or other machinery. This margin is necessary to allow for friction and other losses in belts, shafting, etc., and leakage of engine due to wear in service or neglect.

MINOR ITEMS.

All live steam pipes and fittings and the tops of boilers should be thoroughly lagged with sectional non-conducting covering or its equivalent. Such covering, if of good quality, will last ten or fifteen years and will pay for itself in five years in the saving of heat that would otherwise be lost by radiation. It is important that the pipe covering should be applied with care in order to have the pipe completely covered by the covering, and not merely by the canvass wrapper. The latter should be thoroughly pasted down and the metal bands tightened.

Self-oiling bearings or other continuous oiling devices and an oil filter will save their cost in a year and will last many years.

When properly cared for, the leather belt is the most satisfactory in the long run, but the writer believes that rope transmission will be found to be adapted to quarry work, by the reason of its flexibility and its ability to endure exposure.

Narrow double belts are better than wide single belts of the same weight.

A belt speed of 3,000 feet per minute gives good results. At this speed a double belt, glued joints, one inch wide, will transmit easily four to five horse power if the pull is steady and not jerky.

A rope can be safely run at 4,500 feet per minute, and a one-inch rope at this speed will transmit from a single groove pulley not less than thirteen horse power.

TRANSMISSION OF STEAM TO THE DRILLS.

The steam main should be carried on posts with brackets and can be conveniently protected from rain and excessive condensation by an inverted wooden trough covered at the joints with tar paper or equivalent.

The pipe should be supported every ten feet and should have if possible, a uniform grade in the direction of flow, of not less than one-half inch to ten feet. When a continuous grade cannot be obtained the low points should be provided with drips. The size of pipe for a given number of drills will depend upon the steam required to operate them and upon the distance which the steam has to be carried.

In a large plant, it will pay to put up a good steam line and to protect it with efficient covering, because wet steam will not drive a drill as economically as dry steam. If the steam reaches the drill wet the water should be "dripped" off before entering the drill.

The steam should be shut off from the pipe line when the drills are not needed, as at night or any other considerable period of time.

Gas Engine Power for Quarries.

At present the gas engine is not sufficiently reliable for the uses of the quarry. The writer believes, however, that the gas engine will some day enter this field in those parts of Iowa where coal is expensive and that the power expense of quarrying will thereby be materially reduced. With it will come the air compressor and air drill or the dynamo and the electric drill, both of which have been successful in mining operations.

In this connection, attention is invited to certain tests made by the United States Geological Survey during the period of the Louisiana Purchase Exposition and at the government testing plant established there. These tests can be studied in detail by referring to Bulletin No. 261, United States Geological Survey, obtainable through your Congressman, or by direct application to the Survey at Washington.

Samples	B. T. U. per lb. Dry Coal		Average K. W. at switchboard		Dry coal per K. W. hour		Rates of economy
	Steam plant	Producer plant	Steam plant	Producer plant	Steam plant	Producer plant	
Alabama No. 2	12,555	13,365	158	148	5.50	2.21	2.48
Colorado No. 1	12,577	12,245	115	148	6.51	2.30	2.83
Illinois No. 3	12,857	13,041	147	148	5.85	2.41	2.43
Illinois No. 4	12,459	12,834	145	148	6.47	2.37	2.73
Indiana No. 1	13,377	13,037	163	148	5.56	2.60	2.14
Indiana No. 2	12,452	12,953	142	149	5.85	2.08	2.81
Indian Territory No. 1	12,834	13,455	143	152	5.44	2.46	2.21
Kentucky No. 3	13,036	13,226	155	148	5.68	2.57	2.21
Missouri No. 2	11,500	11,882	152	128	6.62	2.30	2.88
West Virginia No. 1	14,198	14,396	146	148	5.25	2.12	2.48
West Virginia No. 4	14,002	14,202	157	148	4.87	1.74	2.80
West Virginia No. 9	14,616	14,580	154	149	4.66	2.14	2.18
West Virginia No. 12	15,170	14,825	151	148	4.75	2.02	2.35
Wyoming No. 2	10,897	10,656	135	149	7.94	2.78	2.85
Averages	13,037	13,192	......	......	5.71	2.29	2.49

In the above table are shown the principal results of steam and producer gas engine tests of certain soft coals, some of which are comparable with Iowa coals. Fourteen tests are here quoted. The favorable showing of the producer gas engine in these tests is significant. While it is true that the steam engine used was a simple non-condensing engine having a "water-rate" of 23.6 pounds, it is also true that the gas engine in the large sizes is still in an experimental stage, especially in those features of its design and operation which affect its utility in plants where only ordinary skill can be expected to be exercised.

Of the coals listed in the above table, Missouri No. 2 resembles most closely the Iowa coals—its principal proportions being

Moisture	11.60
Carbon, volatile	35.28
Carbon, fixed	38.28
Ash	14.84
Sulphur	4.56
Calorific value	11500 to 11882

and the average of Iowa coals being

Moisture	13.16
Carbon, volatile	33.36
Carbon, fixed	39.69
Ash	13.76
Sulphur	4.65
Calorific value	10019 to 11027

"The high percentage of sulphur in the coal did not add to its value as a producer fuel," is a remark made in the government report in connection with these tests, which sentiment has been modified materially in the view of later experience to which reference is had below.

The lack of correspondence between the relative values of the several coals in the table for steam and producer tests indicates that a given producer may be better adapted for handling a wide variety of coals than is a given boiler furnace.

The table also shows that for these tests and conditions the percentage saving in fuel of the producer over the steam plant is greater for the poorer coals, and this is an entirely reasonable view because the volatile constituents of the coal in the producer escape only through the engine cylinder in which their combustion is quite completely effected; whereas, with steam generation with volatile fuels under a boiler, various and large proportions of the volatile matter escape to the chimney unburned.

The tests above quoted were largely in the nature of preliminary tests and considerable difficulties were met with in obtaining reliable results.

In the year following the exposition, viz., 1905, better arrangements were available for the tests, and the matter was again entered into much more thoroughly. A notable change in the conditions surrounding the second series of tests was in their length. It was possible to secure continuous periods of operation for each test of from forty to sixty hours, which was not possible in the earlier tests.

Samples	B. T. U. Per lb. Dry Coal	Ash	Sulphur	Dry Coal Per K. W. Hour.		Ratio
				Steam	Producer	
Illinois No. 6	12762	16.0	4.6	7.13	2.40	2.98
7	12730	18.9	4.15	5.85	3.50	1.67
8	12020	11.6	4.64	7.41	2.31	3.20
9	12438	11.5	4.92	7.00	2.38	2.94
10	12929	10.6	1.35	7.70	1.95	3.95
Washed 11	12348	10.8	2.09	6.02	1.82	3.32
11	13370	11.5	1.65	6.62	4.00	1.65
13	12600	10.2	1.66	6.12	2.14	2.87
14	12060	12.4	4.16	7.16	2.10	3.40
15	11749	13.5	4.06	6.82	2.18	3.14
16	12874	10.3	1.47	5.70	2.25	2.54
18	12970	10.0	4.59	6.40	2.03	3.15
19	13000	9.4	0.53	5.65	1.79	3.16
Average						2.92
Indiana No. 5	12600	11.5	5.00	6.41	2.20	2.92
" " 6	12505	12.5	4.71	6.41	2.32	2.77
Kansas No. 5	....	10.2	3.18	....	2.02	....
Kentucky No. 5	14500	4.0	0.47	4.83	1.79	2.69
Dakota lignite	....	11.4	3.54	....	2.55	....
West Virginia	14500	3.5	0.82	4.64	1.36	3.41
Wyoming	10518	15.3	7.36	7.96	2.40	3.31
Brazil	9900	23.4	2.94	8.85	3.12	2.84
Average except Illinois						2.99
Average of all						2.93

The preceding table gives a comparative summary of a number of soft coals tested in 1905, both on the steam plant and the producer plant. The results are very interesting and confirm in a general way the advantages of the producer plant indicated by the earlier tests. In the earlier tests, as shown in the first table, the ratio of economy of the producer to the steam plant was 2.49. In the tests of 1905, the average ratio for the Illinois coals was 2.92, and for sundry other coals used, 2.99, and for the nineteen coals as shown in the second table, the average was 2.93.

The following summary of the 1905 tests is taken from Bulletin No. 290, United States Geological Survey.

"The results of the majority of the tests have been exceedingly gratifying, official records having been made as low as 0.95 pound of dry coal per hour burned in the producer per electrical horsepower developed at the switchboard, or 0.80 pound of dry coal per hour burned in the producer per brake horsepower, on the basis of an assumed efficiency of 85 per cent for generator and belt.

"Throughout the tests a constant effort has been made to do away with unnecessary appliances. This effort has furnished valuable and interesting information and has centered attention on several radical changes in the details of producer gas plant construction.

"It was found at an early date that more or less sulphur was passing the purifier and entering the engine cylinders. Investigations by the chemists showed that purifiers consisting of oxidized iron filings and shavings are fairly efficient for coals containing little sulphur—1 per cent or less; but it was found that for coals containing larger percentages of sulphur the purifier became completely exhausted after about six or eight hours. Mixtures of lime and shavings were tried, but with little success. As a result of these investigations, the purifier has been discarded, and the gas, carrying its full percentage of sulphur, has been charged directly into the engine cylinders. This method of operating has been going on for many months, and no ill effects have been discovered, though coal has been used containing as high as 8.1 per cent of sulphur.

"One feature of the plant as installed was the economizer, used for preheating the air for the blast. A series of experiments has shown no effect on the chemical composition of the gas or on the efficiency of the plant when air at ordinary atmospheric temperature was substituted for preheated air. As a result the economizer, as an economizer, has been discarded, and the construction of the plant again simplified.

"Other modifications and changes are under investigation at the present time, the most important, from an economic standpoint, relating to the utilization of slack coal in producers."

In addition to the above the writer presents the principal results of a test of a hard coal producer gas engine made under his direction, in the spring of 1906. The engine was a three-cylinder, vertical, Fairbanks Morse engine, using gas generated from anthracite pea coal in a suction gas producer, also manufactured by the Fairbanks Morse Co. The unit is rated at 150 brake horsepower at 250 revolutions per minute, and was guaranteed to give one brake horsepower hour for not to exceed one and one-half pounds of anthracite pea coal for all loads above seventy-five brake horsepower.

Revolutions per minute	Brake load, horsepower	Pounds coal (as fired) per brake horsepower per hour	Cost per brake horsepower hour at $6.00 per ton
250	40.1	1.511	$0.00453
250	82.7	1.157	.00347
250	156.9	0.999	.00299

Two tests were also made on this engine under service conditions, viz.: belted to a 75 K. W. alternating current generator. In addition to the lighting load, electrically driven pumping machinery can be operated from this generator.

Fig. 6 shows the load curve (A) during a service run with lighting load only and the load curve (B) for the combined load, the usual operating conditions, stand-by losses included.

At $6.00 per ton the cost of fuel per K. W. hour at the switchboard for the load A was $.01207 including fuel for banking and starting, and for the load B was $.00639 including also the standby losses.

Soft coal from Illinois which was used for a Corliss engine unit in the same plant cost $3.40 per ton.

For the purpose of comparison with this test, we may consider the case of a simple Corliss engine similar to that used in the government tests at St. Louis. The average coal consumption of that engine, according to table on page 177, was 5.71 pounds per K. W. hour. If this coal cost $3.00 per ton the cost of the coal per K. W. hour would be $0.0085, which can be compared directly with the values given in connection with the Algona test.

It is difficult at this time to predict the immediate future of the producer gas engine, but the writer believes that this type of prime mover is destined to be a formidable rival of the steam engine, and as the price of fuel increases the field for the producer gas engine will enlarge. At present there is a question whether it will pay to install a producer gas engine where coal is cheap. The only advantage would be the compliance with the smoke regulation, but as a financial proposition it may be stated that owing to the fact that a producer gas engine installation costs probably from 50 per cent to 60 per cent more than a steam engine plant which would be its alternate, it will not pay to consider the installation of the gas producer plant with coal costing $1.25 or less per ton.

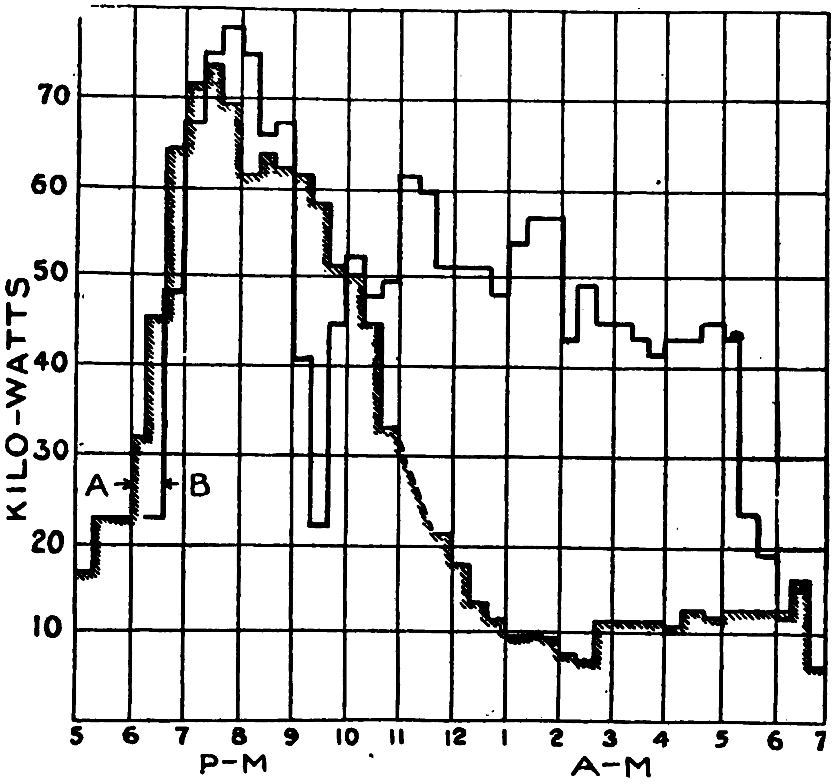


FIG. 6—Test of producer gas engine.

A.—Load curve of Algona producer gas engine, Mar. 15-16, '06.
Fourteen hour test. Output 400 K. W. hours.
Anthracite pea coal per K. W. H. = 4.10 lbs.
Fuel cost per K. W. H. = $0.0123.
Load factor 18 per cent.

B.—Load curve of Algona producer gas engine, Mar. 16-17, '06.
Twelve hour test. Output 589 K. W. hours.
Anthracite pea coal per K. W. H. = 2.23 lbs.
Fuel cost per K. W. H. = $0.00699.
Load factor 27 per cent.

The question of the mechanical and operative advantages and disadvantages of the gas engine will not be discussed here except to say that there is no reason why the gas engine can not be used satisfactorily for the generation of electrical current for light, pumping and power.

The Geology of Quarry Products

BY

S. W. Beyer and Ira A. Williams

WITH AN INTRODUCTION

BY

SAMUEL CALVIN

THE GEOLOGY OF QUARRY PRODUCTS

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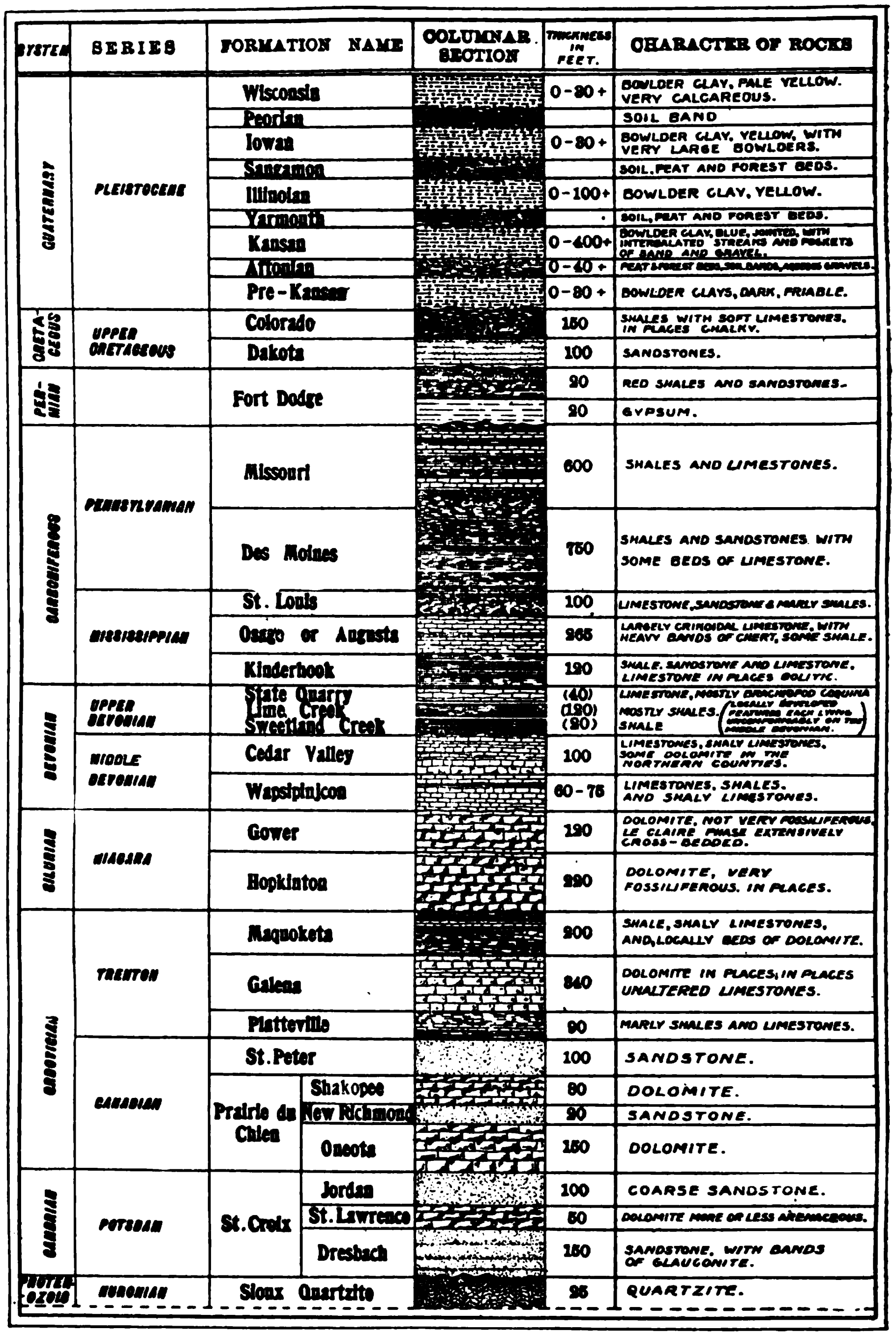

SYSTEM	SERIES	FORMATION NAME		COLUMNAR SECTION	THICKNESS IN FEET.	CHARACTER OF ROCKS
QUATERNARY	PLEISTOCENE	Wisconsin			0-20+	BOWLDER CLAY, PALE YELLOW. VERY CALCAREOUS.
		Peorian				SOIL BAND
		Iowan			0-30+	BOWLDER CLAY, YELLOW, WITH VERY LARGE BOWLDERS.
		Sangamon				SOIL, PEAT AND FOREST BEDS.
		Illinoian			0-100+	BOWLDER CLAY, YELLOW.
		Yarmouth				SOIL, PEAT AND FOREST BEDS.
		Kansan			0-400+	BOWLDER CLAY, BLUE, JOINTED, WITH INTERCALATED STREAKS AND POCKETS OF SAND AND GRAVEL.
		Aftonian			0-40+	PEAT & FOREST BEDS, SOIL BANDS, AQUEOUS GRAVELS.
		Pre-Kansan			0-30+	BOWLDER CLAYS, DARK, FRIABLE.
CRETACEOUS	UPPER CRETACEOUS	Colorado			150	SHALES WITH SOFT LIMESTONES, IN PLACES CHALKY.
		Dakota			100	SANDSTONES.
PERMIAN		Fort Dodge			20	RED SHALES AND SANDSTONES.
					20	GYPSUM.
CARBONIFEROUS	PENNSYLVANIAN	Missouri			600	SHALES AND LIMESTONES.
		Des Moines			750	SHALES AND SANDSTONES WITH SOME BEDS OF LIMESTONE.
	MISSISSIPPIAN	St. Louis			100	LIMESTONE, SANDSTONE & MARLY SHALES.
		Osage or Augusta			265	LARGELY CRINOIDAL LIMESTONE, WITH HEAVY BANDS OF CHERT, SOME SHALE.
		Kinderhook			120	SHALE, SANDSTONE AND LIMESTONE, LIMESTONE IN PLACES OOLITIC.
DEVONIAN	UPPER DEVONIAN	State Quarry			(40)	LIMESTONE, MOSTLY BRACHIOPOD COQUINA
		Lime Creek			(120)	MOSTLY SHALES. (LOCALLY DEVELOPED FEATURES EACH LYING UNCONFORMABLY ON THE MIDDLE DEVONIAN.)
		Sweetland Creek			(20)	SHALE
	MIDDLE DEVONIAN	Cedar Valley			100	LIMESTONES, SHALY LIMESTONES, SOME DOLOMITE IN THE NORTHERN COUNTIES.
		Wapsipinicon			60-75	LIMESTONES, SHALES, AND SHALY LIMESTONES.
SILURIAN	NIAGARA	Gower			120	DOLOMITE, NOT VERY FOSSILIFEROUS, LE CLAIRE PHASE EXTENSIVELY CROSS-BEDDED.
		Hopkinton			220	DOLOMITE, VERY FOSSILIFEROUS. IN PLACES.
ORDOVICIAN	TRENTON	Maquoketa			200	SHALE, SHALY LIMESTONES, AND, LOCALLY BEDS OF DOLOMITE.
		Galena			340	DOLOMITE IN PLACES; IN PLACES UNALTERED LIMESTONES.
		Platteville			90	MARLY SHALES AND LIMESTONES.
	CANADIAN	St. Peter			100	SANDSTONE.
		Prairie du Chien	Shakopee		80	DOLOMITE.
			New Richmond		20	SANDSTONE.
			Oneota		150	DOLOMITE.
CAMBRIAN	POTSDAM	St. Croix	Jordan		100	COARSE SANDSTONE.
			St. Lawrence		50	DOLOMITE MORE OR LESS ARENACEOUS.
			Dresbach		150	SANDSTONE, WITH BANDS OF GLAUCONITE.
PROTEROZOIC	HURONIAN	Sioux Quartzite			25	QUARTZITE.

PLATE XXX—Geological section of Iowa.

CHAPTER IV

INTRODUCTION.

NOTES ON THE GEOLOGICAL SECTION OF IOWA.*

By SAMUEL CALVIN.

The columnar section is not drawn to scale. The approximate average thickness is indicated in the appropriate column.

The Sioux quartzite occupies only a few acres in the northwest corner of the state, and in this locality it is Cretaceous sediments which are found, in place, abutting against it. That it is pre-Cambrian in age admits of no doubt, and that it is the equivalent of the Baraboo quartzite of Wisconsin is equally certain. The 25 feet exposed in Iowa is only a small part of the thickness of this formation.

The Cambrian sandstones are exposed by the erosion of the river valleys in the northeastern part of the state. The basal contact with the older pre-Cambrian quartzites is not seen in Iowa; a thickness of fully 700 feet of this formation lies below the level of the Mississippi River at Lansing and New Albin. These sandstones have been referred to the Upper Cambrian, or Potsdam series, in the geological reports of Iowa and Wisconsin, and they have been very generally spoken of, collectively, as *The Potsdam sandstone* in discussions on the geology of the upper Mississippi valley. The special formation name, St. Croix, and the names applied to the smaller divisions, have been adopted from the reports on the geology of Minnesota.

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*Re-printed with some emendations, from *The Journal of Geology*, October-November, 1906, Chicago, Illinois.

The Prairie du Chien limestone.—Following the Potsdam sandstone of the Cambrian System is a succession of beds, chiefly dolomites, which was originally recognized by Owen under the name of *The Lower Magnesian limestone.* Owen's name for this assemblage of strata was current among western geologists for many years after the publication of his reports, and in some recent publications the old name has been retained. It has been shown that the *Lower Magnesian limestone* consists of three geological units in its exposures near the Mississippi river, a sandstone member, *The New Richmond sandstone,* lying between masses of dolomite. The lower dolomite has been called *Oneota limestone* by McGee, while the upper member was described as the *Shakopee limestone* by the geologists of Minnesota. In the Lancaster folio, recently published by the United States Geological Survey, Owen's *Lower Magnesian* has been given a geographic name, and is henceforth to be known as *The Prairie du Chien* limestone. In the earlier reports on the Iowa Geological Survey McGee's name, *Oneota limestone,* was extended so as to make it the full equivalent of Owen's *Lower Magnesian.* Restricting the use of the term Oneota to the geological unit to which it was originally applied, and substituting *Prairie du Chien* for the original non-geographic term applied by Owen, the reason for the arrangement adopted in the columnar section will be apparent.

The St. Peter sandstone needs little comment further than to say that McGee, in his *Pleistocene History of Northeastern Iowa,* extended the application of the term downward so as to make it include the Shakopee and New Richmond of what is now termed *The Prairie du Chien* stage. It was assumed that the two sandstones are related, and the intervening Shakopee limestone is only an incident. Apart from the fact that they are made of quartz grains, the two sandstones have nothing in common. The New Richmond lies in thin beds; the surface of the beds is often ripple-marked; the individual grains, in the most perfect way imaginable, show secondary enlargement; some parts of the formation have been converted into a fair quality of quartzite. None of these things characterize the St. Peter.

The Platteville and Galena limestones.—The confusion which has arisen in connection with the use of the terms "Trenton" and

"Galena" as applied to certain Ordovician limestones of the mid-western states, and the probable causes of such confusion, are discussed in the "Geology of Dubuque County," in Volume X of the *Iowa Geological Reports*. The assemblage of strata covered by the two names conjoined is divided by a persistent band of shale and shaly limestone carrying *Orthis subaequata* and *O. tricenaria* of Conrad as characteristic fossils. This band has been called the "Green Shales" in some Minnesota and Iowa reports. All the beds above the "Green Shales" are dolomitic at Dubuque, and, so far as concerns this locality, they have been consistently known as the Galena limestone ever since the publication of the report on the *Geology of Iowa* by James Hall in 1858. In localities where these beds are unaltered limestones, they have usually been spoken of as Trenton. Lithology, and not stratigraphy, was the basis of the classification. It is now proposed to use the term "Galena" for all the strata above the "Green Shales," whether they are dolomitic, as at Dubuque, or are non-dolomitic, as along the river at and above Decorah. Bain's name, "Platteville," is acceptable for the beds below the top of the "Green Shales."

The Maquoketa shales were so named by White in his report on the *Geology of Iowa*, published in 1870. The beds are, in part only, the equivalent of the Cincinnati shales of Meek and Worthen, of the Richmond shales of some recent authors, of the Hudson River shales of the New York geologists.

The Niagara limestone.—Lithologically, the Niagara series of Iowa is wholly unlike that of New York. There are no sandstones, no shales, practically no unaltered limestones. In the mid-west the Silurian is represented by a great body of dolomite in which there is more or less commingling of the Clinton and Niagara faunas of the region farther east. In some cases a number of life zones may be recognized. *Syringopora tenella* characterizes one of these; *Pentamerus oblongus*, another; another has *Caryocrinus*, *Eucalyptocrinus*, and related forms as diagnostic types; and others, like that carrying *Dinobolus conradi*, are marked by still different species. But these zones are not well set off one from the other, and in many localities there is more or less of intermingling of forms from adjacent zones. The lower part of the Niagara limestone, including the zones between the base of the formation and the top of the Pentamerus-bearing beds, is quite distinct from the upper portion which includes what have been called the Le Claire and the Anamosa limestones. In the earlier volumes of the current series of *Iowa Reports* the lower phase was designated the Delaware stage, and the upper has been called by Norton the Gower stage. The term "Delaware," however, as the name of a geological unit, was used by Orton for a phase of the Ohio Devonian as early as 1878, and it is proposed[*] to use "Hopkinton" in place of the preoccupied term "Delaware" for the lower phase of the western Niagara. All the characteristics of this stage are well displayed in the quarries and ravines within a radius of two or three miles around Hopkinton in Delaware county, Iowa.

The Devonian system.—The Devonian is represented in Iowa by an assemblage of sediments carrying characteristic Devonian faunas. It is not possible, however, definitely to correlate any part of the western Devonian with any part of the sediments referred to the same system in New York. There is certainly nothing west of the Mississippi which can be said to represent the Helderberg or Oriskany of the East, and the New York Corniferous, or Onondaga, is but doubtfully indicated by a few species. The faunal relations of our Devonian, so far as it is possible to recognize such relations, are with the divisions generally known as Hamilton and Chemung. The conditions of sedimentation were different in the two areas, mechanical sediments and turbid waters prevailing in one, clear seas and organic deposits characterizing the other; geographically the basins were separate; a very large proportion of the species are quite distinct and are useless for purposes of correlation. Of the species which are common the order in which they arrived in the respective basins is not the same, some of the upper Devonian forms of New York appearing early in Iowa, while some of the earlier ones came late. In a general way, therefore, but not in any way definite or specific, the Middle and Upper Devonian may be recognized; but not even in the most general way can we point to anything corresponding to the Lower Devonian of the New York section. Indeed, the remarkable lung fish, Dipterus, which elsewhere is found only in the Upper

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[*] See report on the Geology of Winneshiek county, vol. XVI, page 60.

Devonian, occurs in Iowa in formations which have been tentatively referred to the Middle Devonian, as well as in formations which have been correlated with the upper division of this system. The system has been divided in Iowa on the basis of an apparent unconformity; faunally the two divisions are not very distinct. The intimate faunal relations between the Independence shales, near the base of our Devonian, and the Lime Creek shales, above the unconformity near the top, are noted in the reports on Cerro Gordo and Buchanan counties. The three units referred to the Upper Devonian—the Sweetland Creek shales, Lime Creek shales, and State Quarry limestone—do not lie one above the other, but each is locally developed and appears to lie unconformably on the Cedar Valley limestones.

In Cedar, Linn, and Scott counties the Devonian follows the Silurian conformably, but in the northern counties, Howard, Winneshiek, and Fayette, there is a record of subsidence due to crustal warping after the Devonian was fairly well advanced, and the rocks of this later system overlap the whole Niagara, and, in the counties named, their eastern edge rests on deeply eroded Maquoketa.

The Lower Carboniferous, Mississippian.—It is possible, indeed probable, that there is an unconformity between the Devonian and Lower Carboniferous, but it has not been positively demonstrated. The actual contact of Devonian and Kinderhook has not been observed. The faunal break is not exceptionally great. The stromatopores, favosites, and most of the other corals characteristic of the Devonian do not appear in the Kinderhook, and the same is true of the Stropheodontas, Strophonellas, and Atrypas; but the Orthothetes, Rhipidomellas, Spirifers, and Cyrtinas have pronounced Devonian relationships. *Productella pyxidata* and *Ptyctodus calceolus,* collected in the Kinderhook of Missouri, furnish other points of affinity between the Kinderhook and Devonian faunas. On the other hand, leaving out Productella, the Productidæ of the Kinderhook are decidedly Carboniferous, and the fish fauna in general points unmistakably in the same direction. The Burlington limestone and the Keokuk limestone of the earlier geologists of Iowa and Illinois have been united under the term "Osage" or "Augusta." While the two alternative names are not quite synonymous, it is probable that geologists will unite on the term "Osage" for the assemblage of limestones, cherts, and shales under consideration. So far as concerns Iowa, the St. Louis limestone brings the Mississippian to a close, and this formation remains as originally defined, the line between the Osage and the St. Louis being drawn at the pronounced unconformity at the top of the Warsaw beds. When the later Mississippian, the Kaskaskia or Chester, was deposited, the shore lines, so far as now known, lay outside the limits of our state. That the greater part of the Mississippian was characterized by comparatively arid climate is supported by many lines of evidence.

The Pennsylvanian series includes the productive Coal-Measures and presents the usual characteristics, biologic and lithologic, of equivalent deposits in other parts of the world. One of the most pronounced unconformities in the Mississippi valley occurs between the Upper Carboniferous and the older formations. When the Pennsylvanian series began, the shore-line was probably as far south as Arkansas. There are indications that, at that time, Iowa stood higher with respect to tide level than it does at present, and deep erosion trenches were cut in the Silurian, Devonian, and Lower Carboniferous formations. When subsidence allowed the sea to return, it advanced upon a scarred and eroded surface, depositing shales and sandstones of the Des Moines stage in old drainage channels, and over the surface generally, as far to the northeast as Delaware and Jackson counties. In the counties last named remnants of Coal-Measure strata are found in troughs cut in Silurian, even in Ordovician, beds, and similar remnants occur in old river channels cut in the Devonian limestones of Muscatine, Linn, and Johnson counties. The extreme advance of the coal-measure sea was of comparatively short duration. For the greater part of the Des Moines stage, so far as it is represented in Iowa, the shore-line oscillated back and forth over the area now occupied by the valleys of the Des Moines and the Skunk rivers. Within this area there are records of numerous slight movements of elevation and subsidence.

The sediments referred to the Missouri stage follow those of the Des Moines without break. The crustal oscillations seem to have been less numerous; the waters were clearer; the climate was less humid; arenaceous deposits are scarce; limestones and shales make up the bulk of the sediments of this stage; progress was made toward the more arid conditions of the Permian.

The Permian.—The gypsum beds in Webster county, together with the associated red shales and sandstones, have been referred by Professor Wilder to the Permian system. By some writers they have been referred to the Triassic, by some to the Cretaceous. These beds contain no fossils, and their stratigraphic relations are such as to lend no aid in determining their exact position in the geological column. They lie unconformably on deposits of the Des Moines stage; in some places they rest on St. Louis limestone, for erosion had cut through the whole thickness of the Des Moines sediments before conditions favoring the deposition of gypsum began.

The Cretaceous system.—The Dakota and Colorado stages of the Upper Cretaceous are represented in northwestern Iowa by a series of sandstones, shales, and chalky limestones. In his report on the *Geology of Iowa,* published in 1870, White divides the Iowa Cretaceous into the "Nishnabotany sandstone," the "Woodbury sandstones and shales," and the "Inoceramus beds." The sandstones along the Nishnabotna river, as well as those at Sergeants Bluff and Sioux City in Woodbury county, together with some interbedded shales, are referable to the Dakota stage; while the main body of shale and the calcareous Inoceramus beds represent the Fort Benton division of the Colorado. It is not certain that there is any true Niobrara in Iowa. During the long interval between the Upper Carboniferous and the Upper Cretaceous the surface of Iowa was deeply eroded, and it was on such a surface that the Cretaceous sediments of the state were unconformably deposited. Since the Cretaceous, these sediments, which were comparatively thin at the most and imperfectly consolidated, have been extensively removed by erosion, and now occur in more or less isolated patches. On the geological map of Iowa the Cretaceous is indicated over the entire area upon which it was originally spread, the thick mantle of drift covering that part of Iowa making it now impossible to outline the individual remnants.

The Pleistocene deposits.—Iowa was exceptionally fortunate in its location with reference to the movements and marginal limits of the successive ice-invasions of the Glacial epoch. The state, therefore, offers unusual facilities for the study of the relative age and differential characters of the several sheets of drift which make up the great body of mantle rock within the limits of the glaciated area. The succession of the glacial and interglacial stages which have been recognized by members of the national and state surveys is indicated in the columnar section, and the subject will be found discussed in the national and state reports.

THE GEOLOGY OF IOWA QUARRY PRODUCTS.

By S. W. BEYER AND IRA A. WILLIAMS.

The Proterozoic.

The Proterozoic is represented by the Sioux Quartzite, which, while known to underlie a considerable area in the northwest corner of the state, exhibits outcrops over a very limited territory in the extreme northwest corner of Lyon county. Small openings have been made and small quantities of the indurated sandstones have been removed from time to time. While Iowa is capable of producing much larger quantities, owing to lack of transportation facilities the trade is supplied from the quarries at Sioux Falls, South Dakota, and the Pipestone district in Minnesota.

The stone varies from a light pink to a deep purple in color, with shades of red prevailing. It also varies greatly in state of induration, texture and structure. As a rule it is typically quartzitic, presenting the characteristic porcelain-like fracture on freshly broken surfaces. Occasionally it is poorly cemented and may be crumbled between the thumb and fingers. In texture it presents normally a fine even grain, although conglomeratic facies on the one hand and slaty on the other are known. In general the quartzite occurs in fairly heavy to massive beds, in approximately horizontal position or dipping at a low angle. In places the beds thin greatly, lack constancy and even show false bedding.

The normal quartzite affords the most durable structural material native to Iowa, and is especially well adapted for heavy masonry and street paving and all purposes where strength and durability are required. It is also well adapted for use in fronts and trimmings of buildings. It takes and holds a high polish and is desirable for decorative purposes. On account of its great hardness it is expensive to dress and because of this fact will never be used extensively save for the most costly and permanent structures.

The Cambrian.

POTSDAM SERIES.

THE SAINT CROIX SANDSTONE.

Only the uppermost division of the Cambrian is known to occur in Iowa. The principal outcrops are confined to the Mississippi river and its immediate tributaries in Allamakee and Clayton counties and are referred to the Saint Croix stage, supposed to be the equivalent of the Potsdam of New York.

The Saint Croix comprises three rather easily separable members, the Dresbach sandstone, the Saint Lawrence limestone and

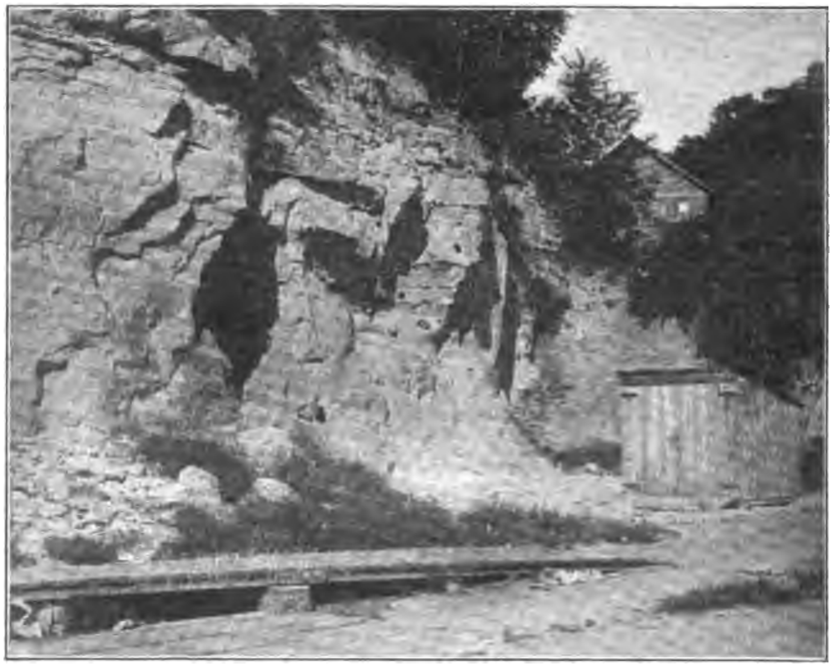

FIG. 7—St. Croix sandstone at McGregor, showing absence of well defined bedding planes.

shales and the Jordan sandstone, named in ascending order. As a rule all of the beds comprising the series are wholly unindurated or are but poorly indurated and as a consequence are of but small importance as a source of quarry products. Certain layers immediately below the Saint Lawrence shales are slightly indurated and have been used to some extent for structural purposes.

As far as known such use has been confined to Allamakee county. The chief openings were made along the Mississippi and immediate tributaries from New Albin to Lansing and from a horizon varying from one hundred to one hundred and fifty feet above the river.

The sandstone carries a calcareous cement, lacks durability and is not readily accessible and deserves mention only as having been used to a very limited extent as a structural material.

The Ordovician.

The Ordovician system of rocks comprises two series, a lower, the Canadian, and an upper, the Trenton. The former may be readily subdivided into two stages, one which is prevailingly a massive dolomite and known in the later publications of the U. S. Geological Survey as the Prairie du Chien limestone,[*] and the other, a well-marked sandstone horizon, the Saint Peter.

The Prairie du Chien limestone comprises a lower massive dolomite which the present Survey has designated the Oneota limestone, a medial sandstone, the New Richmond, and an upper dolomite, the Shakopee limestone. Near the base of the Oneota limestone, above about ten to fifteen feet of arenaceous limestone, there are thirty to forty feet of evenly bedded dolomite, excellently adapted for the various grades of dimension stone and the really only important quarry horizon in the Prairie du Chien limestone.

The beds representing the Saint Peter sandstone are usually not sufficiently indurated to merit consideration as a building stone. Occasional beds are indurated locally and have been developed to a very limited extent.

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[*] In the reports on Winneshiek and Clayton counties, volume XVI of these reports, this stage is called the Lower Magnesian, but this term is now superseded by the one here used in accordance with a recent decision of the Board on Geologic Names of the U. S. Geological Survey. See Lancaster-Mineral Point Folio, page 3

The Trenton series comprise the Platteville, Galena and Maquoketa stages, according to the present terminology adopted by the Survey. All of the members have furnished some structural material, although quarrying operations have been limited to the Platteville and to the dolomitized portion of the Galena. The most important horizon, known as the "Lower Buff Beds," attaining a thickness of more than twenty feet, occurs near the base of the Platteville and is separated by a few feet of shale from the Saint Peter sandstone.

The upper Platteville, while usually thinly bedded and often decidedly argillaceous, is quarried to some extent. The Galena limestone, as it occurs in Dubuque county, affords stone suitable for massive masonry and has been so utilized to a limited extent. To the northward it becomes less magnesian to non-magnesian and is practically worthless for structural purposes. The Galena is separated from the Platteville by a calcareous shale, the "Decorah Shale" of Professor Calvin, the "Green Shales" of the Minnesota geologists, which is worthless save as a possible source of material for cement manufacture.

The uppermost member, the Maquoketa, is of small importance as a source of quarry products. The Middle Maquoketa cherts may prove to be serviceable road material, while the calcareous to dolomitic layers in the Lower and Upper Maquoketa have been quarried locally. The shales of the Lower Maquoketa afford material suitable for the manufacture of Portland cement.

It is probably true that no other rock system is potentially richer in quarry products than the Ordovician. This wealth of material has been but little developed in Iowa. The lack of development is due to several causes. In the first place, first class material constitutes only a small proportion of the entire assemblage of beds. As yet the demand for the waste which could be utilized as crushed stone is small. In the second place the counties in which the Ordovician beds occur are poorly supplied with transportation facilities, away from the immediate vicinity of the Mississippi river. Third and last of the important factors, is the introduction of cheap substitutes for building stone. Stone of usable quality can be obtained in every township, oftentimes on every farm over considerable portions of the Ordovician area. As a consequence, the outlook is not encouraging for the immediate future.

ALLAMAKEE COUNTY.

The Ordovician covers the entire county with the exception of narrow belts along the Mississippi and Oneota rivers and their immediate tributaries, where the beds have been removed through erosive agencies and the Saint Croix sandstone exposed. Good quarry stone occurs at several levels, notably near the base of the Oneota and of the Platteville limestone formations. Above the ten or fifteen feet of arenaceous limestone or calcareous sandstone at the base of the Oneota there are thirty or forty feet of evenly bedded, fine-grained, buff, dolomitic limestone in layers varying from a few inches to three feet in thickness and in blocks oftentimes many feet in width and length. In the eastern portions of the county in the vicinity of New Albin, Lansing and Harpers Ferry the beds have been worked to some extent but are not of especially good quality. In the northwestern portion of the county, the same beds afford material of superior quality for the various grades of masonry, although on account of the absence of suitable facilities for transporting the product, they have been but little developed. Great blocks detached from the parent ledges through the undermining of the friable sandstones below, retain their angularity and otherwise demonstrate their durability though they have been exposed for hundreds of years. At the present time only sufficient quarrying has been done to demonstrate the wonderful possibilities of this horizon as a source of wealth which may in time be utilized.

Above these beds in the basal portion of the Oneota there are occasional beds suitable for structural purposes but as a rule the stone is massive, with only occasional irregular bedding planes, which renders quarrying difficult. Besides, the beds are rather coarse textured, vesicular, and oftentimes arenaceous or cherty. The upper Prairie du Chien beds generally show layers of sandstone and shale interstratified with the dolomitic beds, and possess little to commend them for quarry purposes.

As a rule the Saint Peter sandstone is not sufficiently indurated to deserve notice as a quarry stone. There are a few small

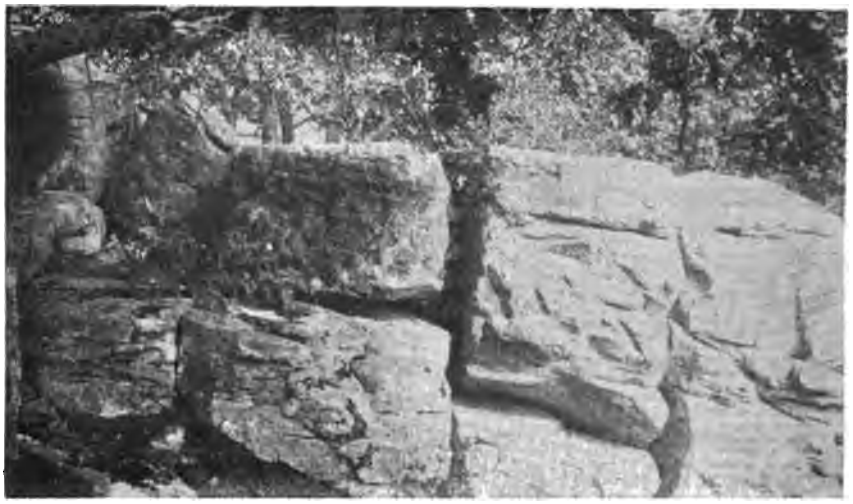

FIG. 8—Effect of weathering on hard beds of Saint Peter sandstone near Heffner's.

patches which are exceptions to the general rule, the stone being sufficiently cemented to be used for rough masonry. It has been so used to a limited extent. Such outcrops may be viewed three miles east of Waukon in the south half of section 27 in Makee township and in the southwest quarter of section 14, Franklin township, near Smithfield. At the latter place the sandstone carries a siliceous cement and forms cliffs thirty or forty feet in height and in some cases breaks into massive angular blocks showing marked ability to resist the agencies of disintegration.

The second important quarry horizon in the Ordovician in the county comes in the lower Platteville and is the equivalent of the "Lower Buff Beds" of the Wisconsin geologists. These beds are separated from the Saint Peter sandstone by five or six feet of greenish or bluish shale and comprise a heavy bedded dolomitic limestone aggregating twenty to twenty-five feet in thickness and composed of layers varying from six inches to three feet or more in thickness. The stone is hard and compact and yellow to buff in color and is capable of furnishing blocks of almost any desired dimensions. These beds are available at numerous points in the county, notably in the valley of Paint creek in Paint Creek township, and in Franklin township, but they have been but little developed.

The Platteville, above the Lower Buff Beds is very variable lithologically. There is a continual alternation of shales and limestones, the limestones predominating. The limestone in general is dull colored, shades of blue prevailing and is often argillaceous. It is generally fine-grained, compact, and occurs in thin beds rarely exceeding six inches in thickness. It breaks with a conchoidal fracture and does not tool easily. Beds which appear to be firm when first quarried, slake readily when exposed to the weather. The upper beds have been quarried to a limited extent near Waukon along Village creek. The stone is a blue to slaty colored limestone, but weathers to various shades of yellow and buff; is hard and fine-grained and occurs in layers of from three to six inches in thickness. The layers are variable in composition and state of induration and, as a consequence, in weather resisting qualities, and they must be selected with considerable caution when used in permanent structures. Similar sections may be viewed north of Postville, where some quarrying has also been done.

The upper quarry beds north of Waukon are overlain by an important deposit of calcareous shale aggregating twenty to thirty feet.

The Galena as developed in Allamakee county affords nothing of importance in the way of quarry products.

CLAYTON COUNTY.

All of the major divisions of the Ordovician are well developed in Clayton county and all supply products of economic importance. The principal quarry horizons are confined to the Prairie du Chien and Galena-Platteville. The outcrops of the Prairie du Chien formation are confined to the Mississippi river and its immediate tributaries in Mendon and Clayton townships, disappearing under the river a short distance north of Guttenberg. For the most part the Oneota division is composed of a coarse, vesicular dolomite, varying from light gray to buff in color and showing but few bedding planes. The lower thirty or forty feet is in ledges varying from two to four feet in thickness and has been quarried at several points near McGregor and

North McGregor. The beds near the top are sometimes cherty and some of the beds carry an abundance of calcite in the caverns. Above the quarry ledges the dolomite is more massive, coarser in texture and shows a decidedly pitted surface when weathered. As a general rule the upper fifty feet of the Prairie du Chien contains thin bedded sandy or shaly layers aggregating about fifteen feet, which are overlain by brecciated and concretionary beds, the Shakopee, aggregating a thickness of about forty feet. While the Prairie du Chien attains a thickness of more than two hundred feet in the county, only the lower beds already described have been quarried, and even these only in a small way.

The Galena-Platteville supplies two well known quarry horizons which correspond in a general way to the "Lower" and "Upper" quarry beds of Dubuque and other counties. The lower horizon is sometimes known as the "Lower Buff Beds" and consists of a fine-grained magnesian limestone which occurs

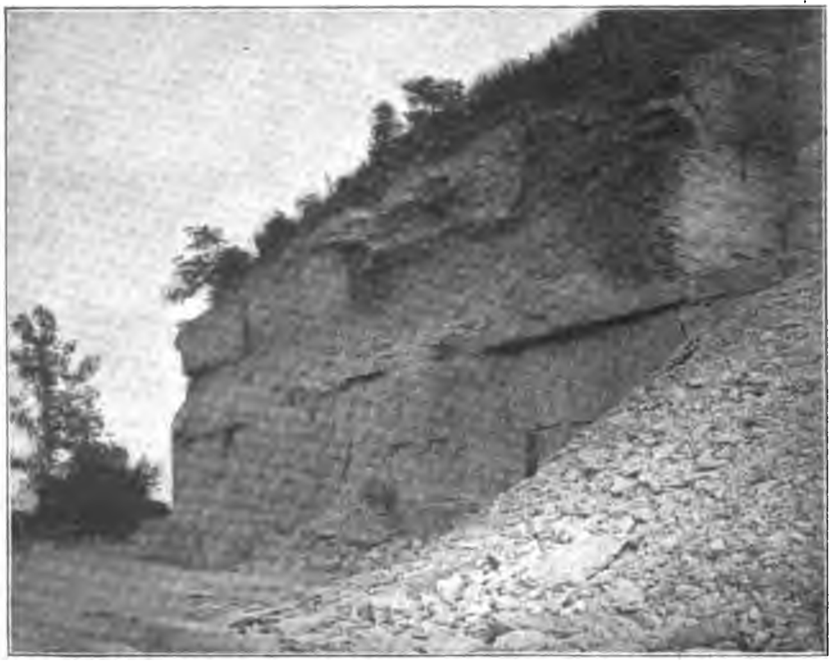

FIG. 9—Quarry in Lower Buff beds at McGregor. Thin-bedded limestone is seen at top.

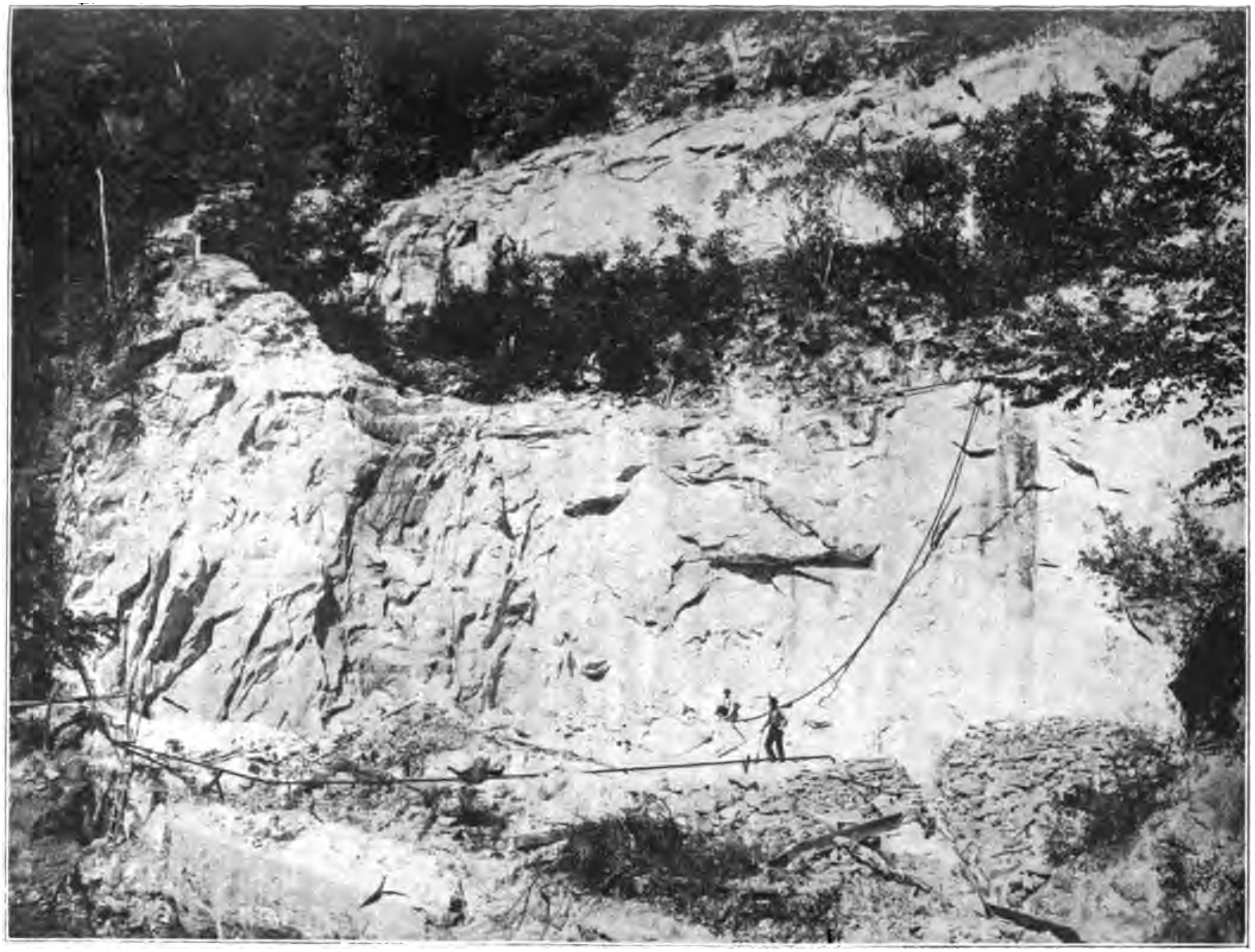

Plate XXXI—Quarry of Clayton White Sand Company, Clayton, Clayton county, Iowa. The beds developed belong to the Saint Peter sandstone and are almost free from impurities.

in layers ranging from eight inches to three or even four feet in thickness. It is blue on fresh faces but upon exposure weathers to a buff color. It breaks readily along bedding planes into slabs of almost any thickness and is cut by sufficient vertical joint planes to facilitate quarrying. These lower beds are being developed near McGregor and Guttenberg and are easily available at numerous other points. They comprise a thickness of from fifteen to twenty feet. The lower quarry beds are overlain by thin bedded, very fine-grained and compact limestone somewhat unevenly bedded and light blue-gray in color. In places these beds are decidedly marly in character. They attain a thickness of twenty-five to thirty-five feet. These thin beds are overlain by the "Green Shales" of the Minnesota geologists. The second important quarry horizon is near the top of the Galena-Platteville and develops the dolomitic beds of the Galena. Numerous quarries have been opened in these beds, including those in the vicinity of Monona, Elkader, Garnavillo, St. Olaf, Farmersburg, in Cox Creek township, the lime kilns at Guttenberg and numerous other points. The upper Galena comprises a heavy bedded, sub-crystalline dolomite, rather coarsely granular, more or less vesicular and buff in color. It weathers very irregularly and presents a rough pitted surface when long exposed. The beds vary in thickness from a few inches to five feet or more. The heavy beds often grade downward into a less heavily bedded mottled zone which is only slightly dolomitic. A few representative sections of the Galena-Platteville are given herewith:

CLAYTON SECTION.

		FEET.
11.	Dolomite, heavy bedded (Galena)	150
10.	Shale, green, at the top of the Platteville.	2-3
9.	Limestone, similar to No. 7	8
8.	Shale, bluish-green	2
7.	Limestone, in regular beds four to eight inches thick, very fine-grained and compact, blue and buff in color. Occurs in thicker layers than No. 5.	15
6.	Shales, green, calcareous, containing lenses and bands of limestones rich in fossils. Among the most common are *Orthis subaequata* and branching monticuliporoids	5

5.	Limestone, thin-bedded and compact, with marly layers one to two inches thick separating many of the beds. Latter are irregular in thickness and range from one to three inches. The marly partings do not always appear on fresh joint faces but stand out on weathered surfaces	25
4.	Limestone, dolomitic, compact, blue when fresh but weathering to buff on exposure; in even beds eight inches to two feet thick, contains few or no fossils. The quarry beds at Guttenberg and McGregor and the "Lower Buff Beds" of some writers	25
3.	Shale, green, immediately overlying the St. Peter sandstone	2
2.	Sandstone (St. Peter)	85
1.	Limestone, Prairie du Chien, to low water in Mississippi	90

GUTTENBERG SECTION.

		FEET.
5.	Limestone, dolomitic, in heavy ledges, vesicular, coarse, buff colored, the typical Galena dolomite	100
4.	Limestone, magnesian, in beds two and three inches to one foot thick, mottled gray and buff, only partially dolomitized and containing sixteen per cent of magnesium carbonate; part of the rock is very fine-grained, compact and gray colored, while other portions are buff and have a rough, coarser feel. Contains some chert in bands and scattered nodules. In these beds are located the quarries supplying rock for the lime kilns at the base of the bluff	60
3.	Limestone, gray, non-magnesian, fine-grained, compact, in thin and uneven beds. Lower portion not well exposed on the ridge, since it is partially covered with talus and soil	85
2.	Limestone, dolomitic, blue when fresh but weathering to buff, beds eight inches to two feet thick. In these "Lower Buff Beds" the quarries are located	15
1.	Sandstone, Saint Peter, not exposed here, but known to rise ten feet above the river	

ELKADER SECTION.

		FEET.
5.	Dolomite, light blue, rather compact, in ledges six inches to two feet thick. Some of the upper strata are separated by thin layers of reddish fissile shale	25
4.	Dolomite, light gray to buff, containing many small cavities, ledges varying in thickness from one to five feet, most of them being over two feet thick	25
3.	Dolomite, buff, massive, weathers irregularly, forming pitted surfaces	70
2.	Unexposed	35
1.	Limestone, non-magnesian, in thin beds, compact, fossiliferous, contains chert nodules arranged in bands, exposed to river	25

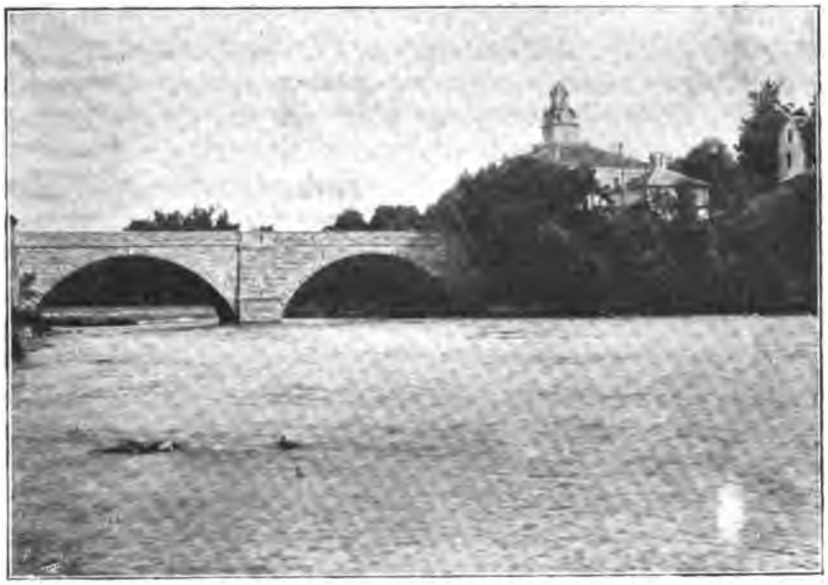

FIG. 10—Stone bridge at Elkader; built of Galena limestone.

Numbers 4 and 5 in the above section are being quarried. Rock for the stone bridge in Elkader was obtained from this quarry. Numerous other sections might be mentioned but the main features are given above.

In places the entire assemblage of beds appears to be non-dolomitic, a feature which is not peculiar to Clayton county but is known to be characteristic of the Galena in northeastern Iowa.

The Maquoketa division of the Ordovician is more highly calcareous than equivalent beds in Dubuque and other counties to the south and yet does not contain beds which have been quarried to any extent in the county. The chert beds above the middle of the formation are sufficiently indurated to be used for road material.

DUBUQUE COUNTY.

The Ordovician system, as developed in Dubuque county, comprises four well marked divisions, the Saint Peter sandstone, the Platteville limestone, the Galena limestone, and the Maquoketa shales. Exposures of the first occur along the Mississippi bluffs from a mile or two above Spechts Ferry to Zollicoffer Lake, a distance of five or six miles. It is represented by a rather ferruginous, variegated, coarse-grained sandstone. It is friable, though the upper beds are sometimes sufficiently indurated to be used as a quarry stone. It has been used to some extent in the vicinity of Spechts Ferry.

The Platteville limestone comprises a series of interbedded limestones and shales, some of the limestone beds being dolomitized. A general section, according to Calvin and Bain, is as follows:

		FEET
8.	Shale to shaly limestone or interbedded limestones and shales.	5
7.	Limestone, bluish, rather coarse-grained, in thin layers ranging from three to six inches in thickness	25
6.	Shale, bluish or greenish, very soft, plastic, with thin lenticular sheets of limestone distributed irregularly through it ("Green Shales")	12
5.	Limestone, bluish beds, weathering brown, coarser grained and less fossiliferous than beds below	5
4.	Limestone, heavier, coarser layers, ledges up to fifteen inches, resist weathering well	5
3.	Limestone, blue, thinly bedded, fine-grained, brittle, fossiliferous, bedding planes very uneven and undulating, weathered surfaces show thin shale partings; shale often quite bituminous. With the two zones above constitutes the "Lower Blue Beds"	20
2.	Limestone, dolomitic, earthy, impure, non-crystalline, hard, firm; beds range from eight inches to three feet in thickness and are well suited for heavy masonry. "The Lower Buff Beds"	18 to 20
1.	Shale, bluish to greenish, weathers to ashen or yellow, "Basal Shale"	3 to 6

Number 2 in this section is the most highly prized for quarry purposes although quite generally obscured by talus slopes. This is the horizon which has been so extensively developed and is deservedly popular for heavy masonry at Minneapolis and Saint Paul.

The following sections in the vicinity of Spechts Ferry give the details of the Platteville.

SPECHTS FERRY SECTION.

		FEET.
11.	Dolomite, thin-bedded, brown, with shaly partings (Galena)	4
10.	Limestone, thin-bedded, imperfectly dolomitized, with fossil brachiopod shells only slightly changed; the limestone brown, earthy, non-crystalline, but evidently of the Galena type	3

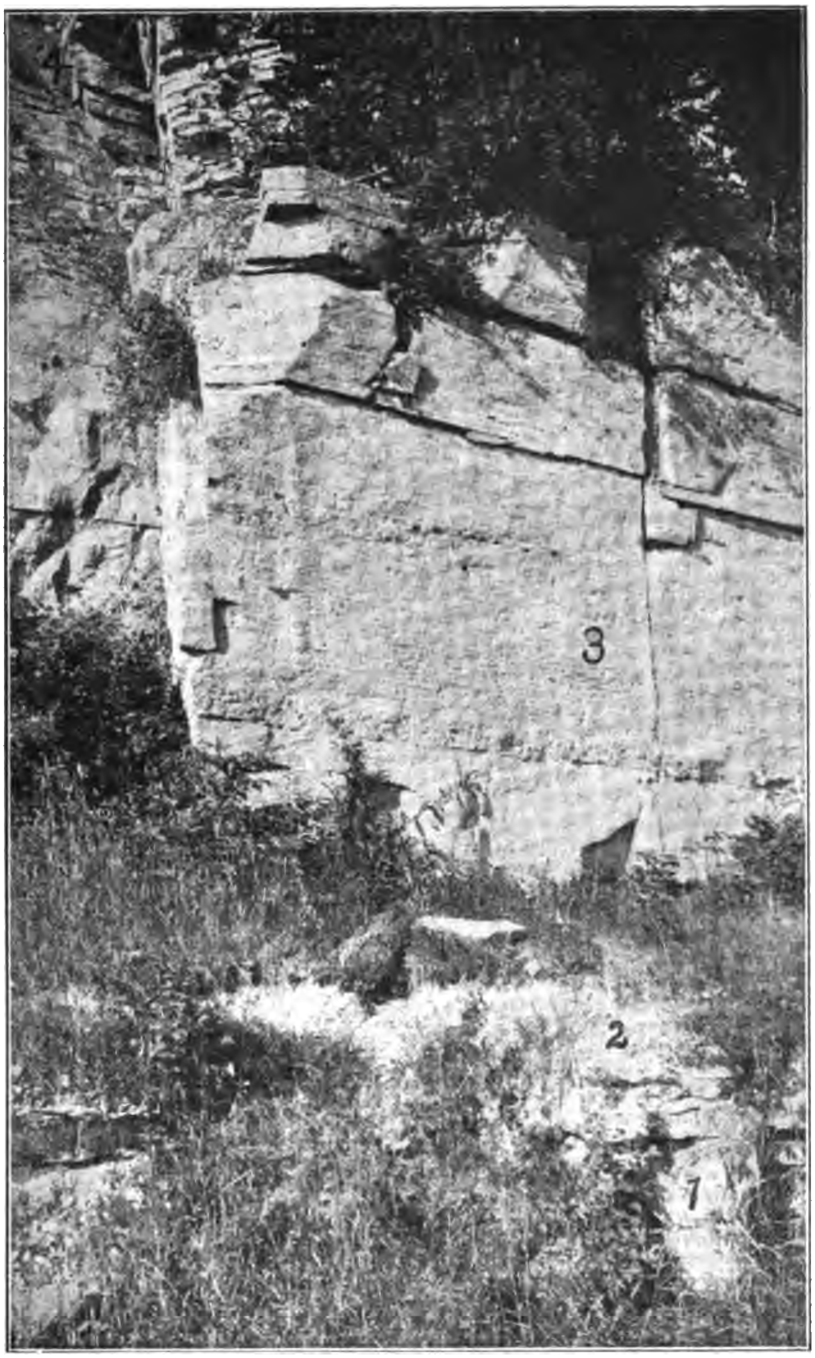

Plate XXXII—View three-fourths of a mile below Spechts Ferry, showing in ascending order: 1. Saint Peter sandstone. 2. Basal shale. 3. Lower Buff beds. 4. Thin, brittle, blue beds.

		FEET.
9.	Limestone, thick, earthy, imperfectly dolomitized (Galena)	3
8.	Limestone, thin beds with much shale in the partings; in part a true shale. This member is almost entirely shaly a few rods above the station on the road leading to Dubuque	5
7.	Limestone, bluish, rather coarse grained, with disseminated fossils; in beds varying from three to six inches in thickness	25
6.	Shale, bluish or greenish, containing occasional thin beds or discontinuous flakes of limestone; the "Green Shales" of the Minnesota geologists	12
5.	Limestone, thin-bedded, bluish, rather coarse-grained, weathering brownish in color	5
4.	Limestone in rather heavy layers which range up to fifteen inches in thickness; bluish on fresh fracture, but weathering to buff on exposure	5
3.	Limestone, brittle, fine-grained, blue, very fossiliferous, breaking up on weathered surfaces into flexuous layers about two inches in thickness	20
5.	Limestone, "Lower Buff Beds," exposed, about	8
1.	Limestone; unexposed to level of water in river, about	45

About three-fourths of a mile below Spechts Ferry the "Lower Buff Beds" show a thickness of twenty feet. A quarry in section 10 of Peru township, two miles below Spechts Ferry, shows the following beds:

		FEET.
5.	Limestone, blue, thin-bedded at the top of the section	2
4.	Shale, the equivalent of the "Green Shales"	8
3.	Limestone, heavy ledges of fairly good building stone, bluish, but weathering into buff on exposed surfaces, equivalent to numbers 4 and 5 of the Spechts Ferry section	10
2.	Limestone, thin-bedded, brittle, blue, fossiliferous	16
1.	Limestone, heavy, "Lower Buff Beds," good quarry stone	10

The Lower Buff Beds are not sufficiently accessible to attain much importance in the county, as a quarry stone. The pure limestone beds above while more readily available are not sufficiently durable to command attention.

The Galena limestone affords an important quarry horizon in the upper beds and one much more generally available than the Lower Buff Beds. Numerous quarries have been opened and operated in the vicinity of the city of Dubuque, near Graf on the Chicago Great Western, and along the Illinois Central at the crossing of the North Cascade road.

The rock quarried is thin-bedded above, ranging from four to ten inches and separated by thin shaly partings becoming heavier below, the beds attaining four feet or more in thickness. The rock is hard, granular, completely dolomitized, and rough and vesicular on exposed surfaces. It does not make a good appearance in dressed stone work but is excellent for ashlar, rough dimension work and heavy masonry. In bridge work, foundations and lower courses in large buildings it makes an excellent appearance.

One of the most complete and representative sections in the county may be seen at the Eagle Point Lime Works. The following sequence of beds may be studied:

		FEET.
15.	Loess-covered slope above the outcropping ledges of Galena limestone, culminating in a prehistoric mound at the summit of the bluff	15
14.	Dolomite in ledges, varying from two to three feet in thickness	10
13.	Dolomite, two or three rather heavy ledges containing large numbers of the problematic fossil, *Receptaculites oweni* Hall. Receptaculites is found sparingly in other members of the section. At this horizon, which will be called the Receptaculites zone, it is exceedingly abundant	10
12.	Dolomite, heavy-bedded, typical Galena, hard, crystalline and relatively free from chert; in ledges three to six feet in thickness	70
11.	Dolomite, bed containing pockets of calcite; the calcite in some cases forming large crystals	3
10.	Dolomite, bed containing large quantities of chert	4
9.	Limestone, ledges showing the characteristics of the typical Galena, hard, compact, crystalline, completely dolomitized, with small amount of chert	18
8.	Dolomite, thick, massive beds with large amount of chert	12
7.	Dolomite, thick beds, crystalline, the ordinary type	6
6.	Dolomite, ledge varying in texture, containing small pockets of calcite and some chert; a single specimen of Receptaculites found in this ledge	4
5.	Dolomite, heavy ledge nearly on a level with the top of lime kiln	3
4.	Dolomite varying in aspect according to degree of weathering; at Eagle Point showing bedding planes 10 to 18 inches apart.	15
3.	Dolomite; massive, crystalline; bedding planes almost completely obliterated	20
2.	Limestone, incompletely dolomitized beds with shaly partings at intervals of six, eight, or ten inches	10

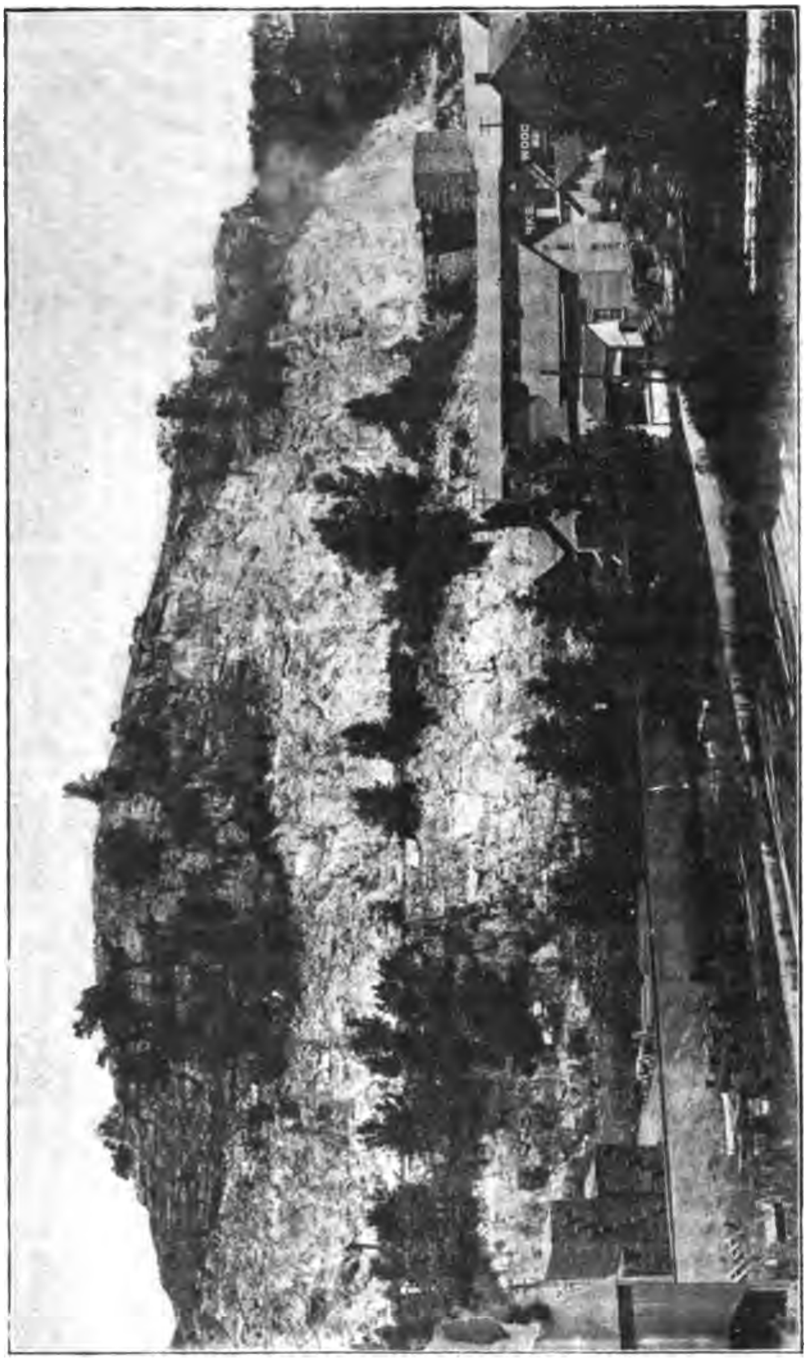

PLATE XXXIII—Quarry and plant of Eagle Point Lime Co., Eagle Point, Dubuque county, Iowa.

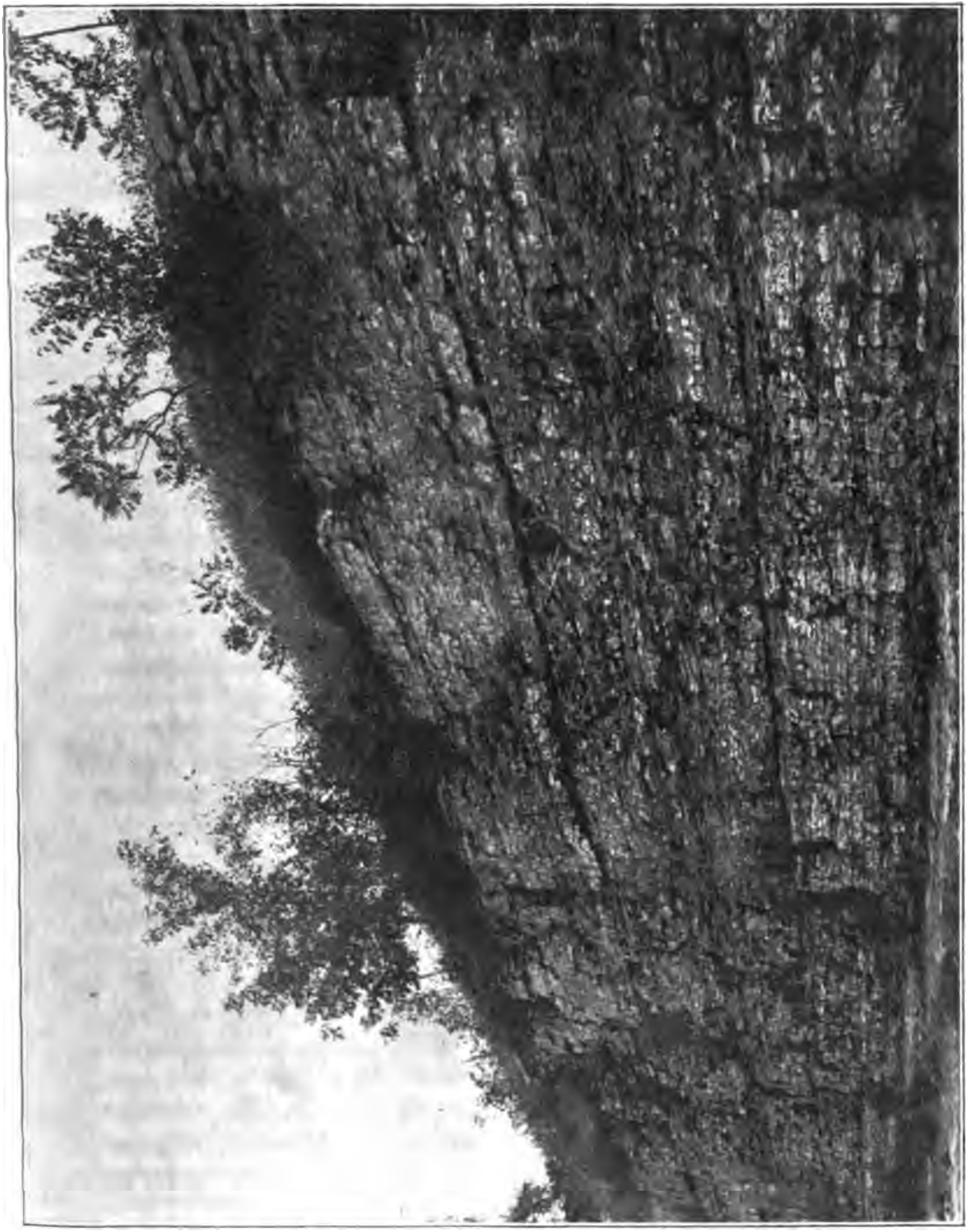

PLATE XXXIV—The chert beds of the Maquoketa afford excellent material for road work. Clermont, Fayette county, Iowa.

	FEET.
1. Limestone, basal ledge of Galena, beginning on top of Platteville limestone and shale bearing *Orthis subæquata* and associated fauna; this lower bed is earthy, incompletely dolomitized, and weathers below into a dark brown or reddish ferruginous clay	2

Numbers 12 to 14 inclusive, comprise the most important quarry beds. The chert beds comprising numbers 6 to the base of 12 are suitable for crushed stone products and are also used for lime. They are not considered desirable for structural purposes.

From the Eagle Point Lime Works the beds dip more or less uniformly to the south and west.

Most of the quarries near Dubuque operate the beds above number 13 in the Eagle Point section. About the middle of this division occurs the "cap-rock" of the miners, a heavy, firm layer about two and one-half feet in thickness with an eight or nine inch layer below it.

The Maquoketa shales contain certain indurated layers throughout and impure, earthy dolomite layers above. None, however, are of sufficient importance to be worthy of special mention for structural purposes and have not been quarried in the county.

FAYETTE COUNTY.

The Maquoketa occupies a considerable area in the northeast corner, practically the entire area north of Turkey river, and appears along the principal streams in the northeast third of the county, notably along the Volga, Turkey, and Little Turkey rivers, and Otter and Bear creeks. Some quarrying has been done in the vicinity of Clermont, the Lower Maquoketa beds being developed. In a few places the less cherty layers of the Middle Maquoketa division yield a material suitable for rough masonry. The chert beds of the Middle Maquoketa as developed at Clermont are dolomitic and cherty and afford an abundance of material suitable for road work, railway ballast and concrete. The beds of the Upper Maquoketa are predominantly argillaceous and are of interest as a possible source of material suitable for the manufacture of Portland cement.

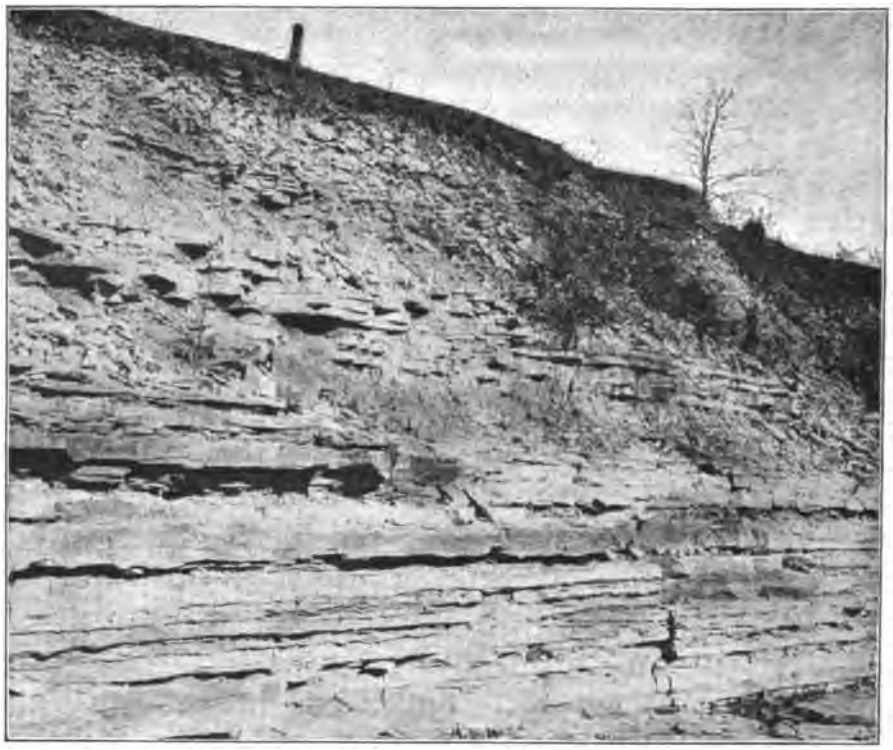

FIG. 11—Beds of *Isotelus maximus* which constitute the basal deposits of the Maquoketa shales; north of the bridge in section 35, Clermont township. The beds have attracted some attention as a possible source of Portland cement materials.

HOWARD COUNTY.

Both members of the Ordovician as developed in Howard county are exposed in the vicinity of Florenceville. Excellent sections of both the Galena-Platteville and the Maquoketa occur in the northern tier of sections in Albion township but as yet the beds are almost wholly undeveloped. The quarry below the mill at Florenceville shows the following beds:

		FEET.
2.	Limestone, irregularly bedded, fine-grained, fossiliferous, with shaly partings; some of the layers represented by detached nodules and irregular lenticular slabs of limestone imbedded in shale........................	10
1.	Limestone, regularly bedded in layers a foot or more in thickness, without shaly partings, rather coarse-grained, beds cut by definite joints, joint faces pitted and roughened by weathering.......................	8

Number 1 furnishes a durable grade of building stone. The rock is magnesian, sub-crystalline and practically non-fossiliferous.

JACKSON COUNTY.

A few outcrops of the Platteville stage of the Trenton series appear in Tete de Mort township from St. Donatus to the Mississippi river and southward. Several small quarries have been opened but have not been operated extensively. Perhaps the largest quarry has been opened near the top of the bluff at Gordons Ferry station. A large amount of material has been taken from the bluff in the vicinity and used in the construction of wing dams along the river. The section exposed presents a massive dolomite in ledges from four to six feet in thickness. The beds are sub-crystalline and quite free from chert. A small quarry near the village of St. Donatus shows the following beds:

ST. DONATUS SECTION.

		FEET.
5.	Dolomite, grayish yellow, in layers three to eight inches in thickness, which are separated by narrow partings of shale; containing a number of fossils in the form of casts or molds	5½
4.	Dolomite, yellowish, similar to No. 5 above, and containing similar fossils	2
3.	Dolomite, yellow, two layers, each about eight inches in thickness, which are separated from each other and from those adjacent by two-inch bands of shale	1¾
2.	Dolomite, rather hard, which is imperfectly separated into layers respectively 2, ½, 2, ¾ and 1½ feet	6¾
1.	Dolomite, yellow, fossiliferous and somewhat vesicular, consisting of layers 2, 3, 2½, ½ and 3 feet in thickness	11

Other quarries have been operated along Tete de Mort creek. A more extensive natural section may be viewed on the northeast quarter of section 24 in the same township. This exposure shows the following succession of beds:

		FEET.
8.	Dolomite, weathered ledge, hard, yellowish gray, indistinctly separated into layers and presenting a very rough surface	6
7.	Dolomite, hard, buff, in three layers, respectively 3, 3 and 1 feet in thickness, the surface showing numerous small cavities	7
6.	Dolomite in heavy layers, yellow, *Receptaculites oweni* abundant near the middle portion	5
5.	Limestone, hard, sub-crystalline, yellow in color, showing numerous cavities, fossils few and poorly preserved	4

		FEET.
4.	Limestone similiar in character to No. 5 above, weathering into indistinct layers three to six inches in thickness.............	5
3.	Limestone ledge consisting of two layers, each about two feet in thickness, containing a number of indistinct fossil remains...	4
2.	Dolomite, hard, buff colored, similar to No. 3.....	3½
1.	Dolomite, hard, massive ledge, yellow, vesicular, down to level of water...............	4½

The upper layers of Galena become thinner with numerous thin shale partings and the Galena cliffs are almost invariably overlain by Maquoketa slopes.

The Maquoketa beds are supposed to be responsible for the slopes which appear at the base of the massive Silurian limestone cliffs which face the Mississippi and its immediate tributaries and also appear in Fairfield and Van Buren townships. The Maquoketa beds are predominantly argillaceous but grade upward into thin layers of indurated limestone interbedded with thin shale layers. These transition beds have been quarried locally at Bellevue and at a few other points in the northeastern portion of the county. The material breaks down rapidly when exposed to the weather and is not of a durable character. A representative section may be seen near the northeast corner of the town of Bellevue. The sequence is as follows:

BELLEVUE SECTION.

		FEET.
8.	Dolomite, hard, massive, crystalline, in heavy layers three to six feet in thickness; indistinct remains of fossils not rare. Niagara limestone..................	13
7.	Limestone, impure, yellowish gray, rather fine-grained, in even layers four to fourteen inches in thickness, weathering into bands of one to two inches; carrying a few fossils; without chert nodules....................................	14
6.	Limestone, argillaceous, earthy, in layers two to six inches in thickness; containing a few fossils. On weathered faces thin partings of shale appear between the layers..........	19
5.	Stone, yellowish, argillaceous, bluish gray where not exposed to the action of the atmosphere; in layers one to three feet in thickness; weathering into narrow bands one to three inches thick. Occasional nodules of chert appear in lower part..	15
4.	Shale, grayish blue, indurated, calcareous, weathers into thin bits; without fossils but carrying a few chert nodules......	3½
3.	Limestone, impure, rather fine-grained, yellow colored, much decayed and showing numerous close lines of lamination..	½

	FEET.
2. Shale, bluish gray, somewhat indurated, weathering into small polygonal and irregular fragments, without fossils...	10
1. Shale, blue, plastic, nonfossiliferous........................	30

In the above section number 8 represents the basal portion of the Niagara limestone, which forms an overhanging cliff. Numbers 6 and 7 represent the transition phase of the Maquoketa, beds which have been quarried to a limited extent. The shales are a possible source of materials suitable for the manufacture of Portland cement.

WINNESHIEK COUNTY.

Good quarry stone is available at a number of horizons in the Ordovician as developed in Winneshiek county. The lowest beds eminently suitable for structural purposes occur near the base of the Oneota limestone in Highland and Pleasant townships. The lower thirty or forty feet, resting directly on the Jordan sandstone, is a light buff, evenly bedded dolomite, fairly

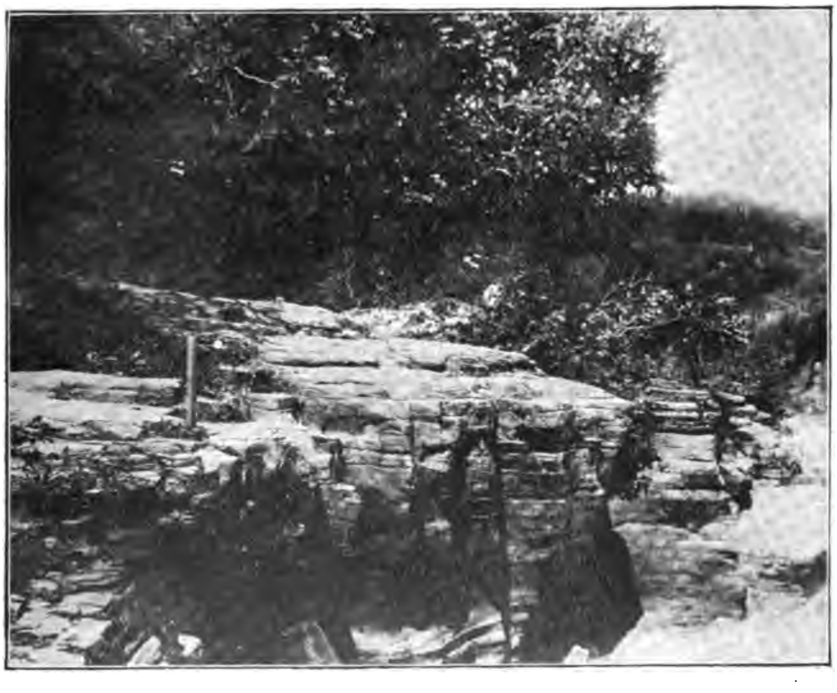

FIG. 12—Exposure of New Richmond sandstone in the northwest quarter of the northwest quarter of section 13, Glenwood township.

uniform in texture and obtainable in blocks of almost any dimensions up to thirty inches in thickness and easily dressed. The outcrops are practically limited to the bluffs facing Bear creek from Highlandville to the county line, and limited outcrops on sections 23, 24, 25 and 26 in Pleasant township. These beds are almost wholly undeveloped in the county on account of the absence of transportation facilities. The upper beds of the Oneota are less desirable for structural purposes on account of their more drusy character, absence of regular bedding planes and general lack of uniformity in texture, structure and composition. At the present time none of the beds belonging to the Oneota are quarried in Winneshiek county.

The Galena-Platteville limestone, as in adjoining counties, affords several well defined quarry horizons. The three divisions recognized by the Minnesota and Wisconsin geologists are very marked here. The lowest division or Platteville limestone is again divisible in three parts, "Lower Buff Beds," "Thin,

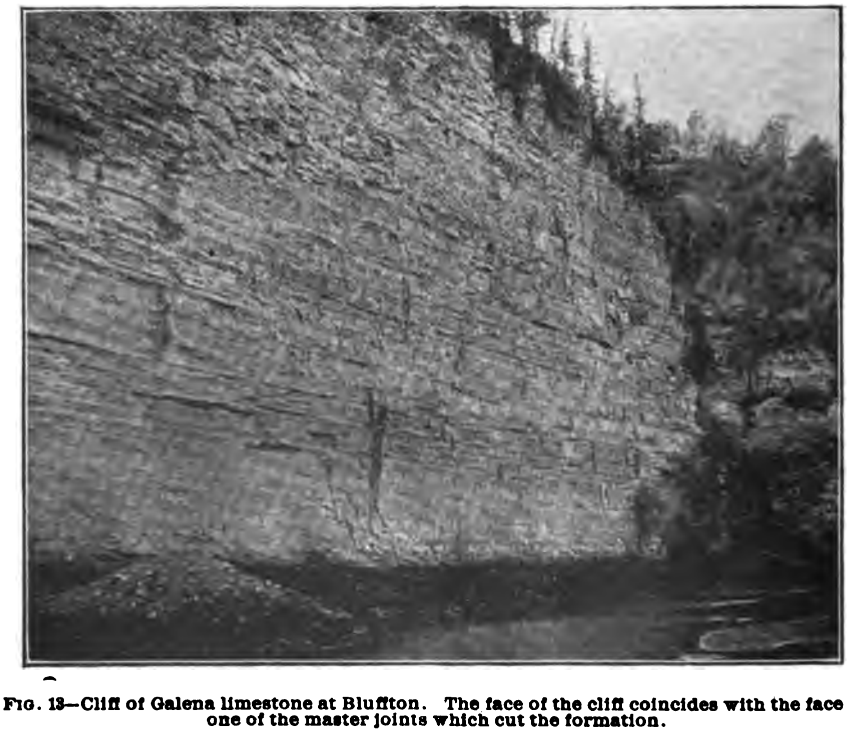

FIG. 13—Cliff of Galena limestone at Bluffton. The face of the cliff coincides with the face of one of the master joints which cut the formation.

Brittle Beds," and "Thicker Quarry Beds" in ascending order. As a whole the Platteville thickens southward and as a consequence is much thicker in Dubuque than in Winneshiek county. The Lower Buff Beds do not exceed five or six feet in the latter county, with eight inch layers, and have been developed at but few points and then in a small way. The heaviest ledges of the Lower Buff Beds occur in the valley of the Upper Iowa in the vicinity of Freeport and east. The Thin, Brittle Beds were quarried formerly to a limited extent, and while apparently in heavy beds where protected, they break down when exposed to weathering influences and are of little economic importance. The uppermost member or Thicker Quarry Bed attains a thickness of from four to eight feet and is evenly bedded. The stone is hard and compact, fine-grained, non-dolomitic limestone, and is of a bluish color. The individual layers range from six to eight inches in thickness, are remarkably uniform and can be obtained in sheets or tablets of almost any desired dimen-

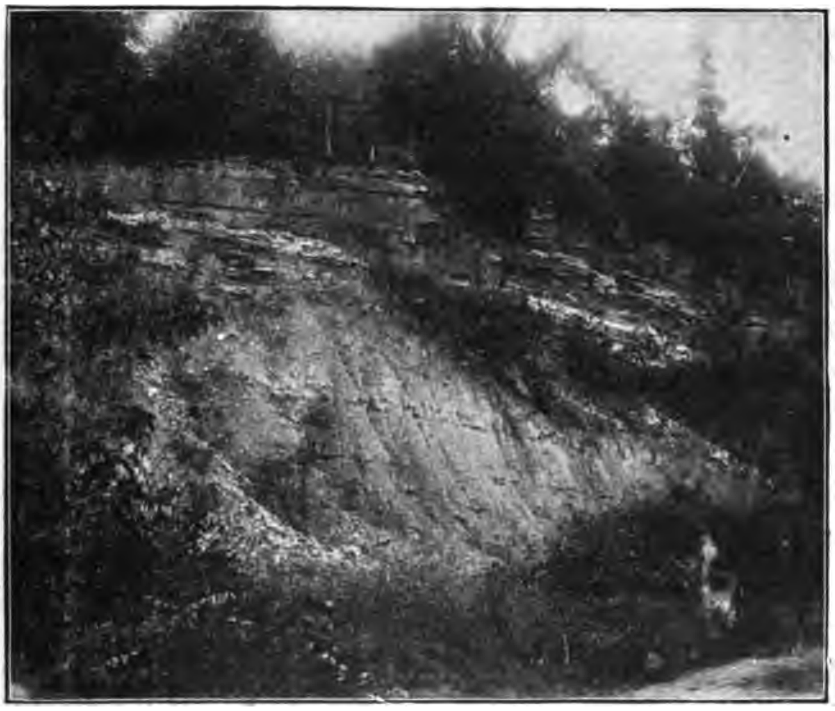

FIG. 14—Exposure of the Decorah shales with overlying basal ledges of the Galena limestone, at the Dugway, Decorah.

sions. This horizon has been quarried extensively in the vicinity of Decorah and Hesper. The beds are composed chiefly of finely comminuted and firmly cemented brachiopod shells. From one of the quarries north of the river at Decorah attempts were made to produce an ornamental stone by sawing into thin slabs and polishing by machinery. The product possessed a rather pleasing appearance and was used to a limited extent for table tops and interior decoration.

A number of quarries have been opened in the Galena limestone, above the level of the Decorah shale. Many are small and were operated only temporarily to supply some immediate local need. At no point does quarrying in the Galena assume commercial importance. The upper quarry of Mr. Halloran is worked at the level of the lower Receptaculites zone, about fifty feet above the Decorah shales. The quality of the stone is not as good as that from the upper part of the Platteville. The bedding is not so regular; the texture is less uniform; much of the stone is liable to split into small chips on long exposure to the weather. There is a large quarry at Nordness which is opened in the upper beds of the Galena. The Maquoketa begins only a few feet above the exposure. The upper beds are badly checked and weathered, but below these there are some quite firm ledges varying from ten to fourteen inches in thickness, with which there is associated a ten inch band of shale. About the middle of the quarry face there is a belt of irregularly bedded concretionary limestone, three feet in thickness, altogether lacking in the homogeneity requisite for good quarry stone. Below this belt there are six feet of more regular and more homogeneous beds, with some of the individual courses fully ten inches in thickness. Another quarry at the same horizon as that at Nordness is opened on the south side of the Yellow river, in the north half of the northeast quarter of section 13, Bloomfield township, on land belonging to the estate of Mr. Melvin Green. The characteristics are the same as at Nordness except that there are several bands of shale, ranging from two or three to ten inches in thickness, interstratified with the limestone. Another quarry which includes the uppermost beds of the Galena is located on the south side of the diagonal road in the southwest quarter of section 17, Bluffton township.

There are other small quarries, worked temporarily or intermittently to supply the purely local demands, near Kendallville, Plymouth Rock and Burr Oak. In the southeast quarter of section 7, Fremont township, are some small quarries opened in beds of dolomitized Galena, a phase of the formation resembling that at Dubuque. Dolomitization here is local, being restricted to an area of three or four square miles. The many other small openings in the Galena limestone are too numerous to be individually noted.

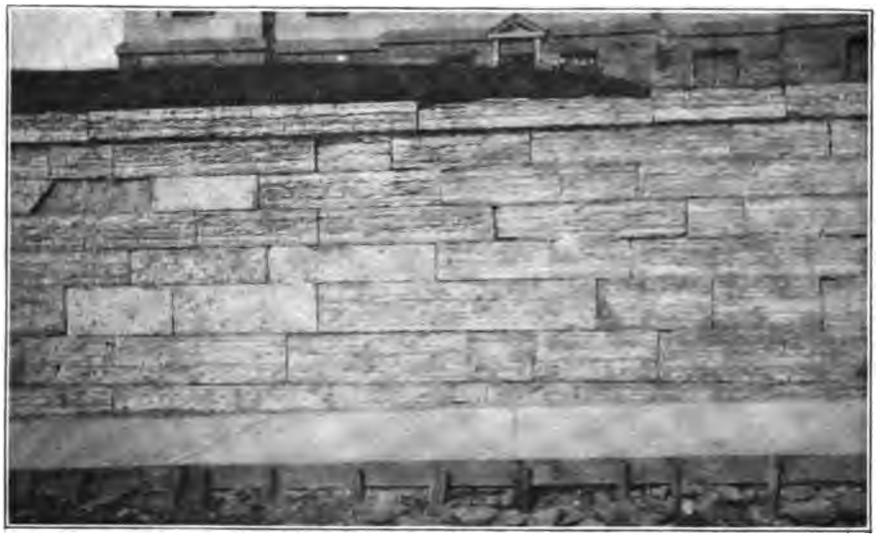

FIG. 15—Portion of retaining wall around Court House Square in Decorah showing unreliable character of Platteville limestone.

Much of the Galena limestone is very unreliable. When quarrying has been carried into the hillside beyond the zone of weathering, the ledges may appear to be thick, firm, durable, suitable for any kind of construction; but after being placed in walls and exposed to alternations of temperature and the chemical effects of air and moisture they split into thin laminæ and eventually break up into small, irregular chips. The effect is well shown in the portions of the old retaining wall still standing around the court house square at Decorah.

Quite an amount of quarrying has been done in the Maquoketa formation. The Isotelus zone is very regularly and evenly bedded, and in a few instances it is firm enough to serve for building stone. One quarry at this horizon, located in the northwest quarter of section 18, Springfield township, is noted by Calvin in connection with the general discussion of the Maquoketa beds of this county.* In some cases the strata lying between the Isotelus zone and the Clermont shale are capable of furnishing a fair grade of building material for rough walls and foundations; but the principal quarry horizon in the Maquoketa is that of the Fort Atkinson limestone. This, not infrequently, is a hard, granular, crystalline dolomite, comparable to some phases of the Galena limestone in Dubuque county. At Fort Atkinson quarries have been worked in this formation for many years, and one of these, located a few yards west of the old fort (Fig. 16), is capable of yielding blocks of any desired dimensions up to three feet in thickness. Another quarry in

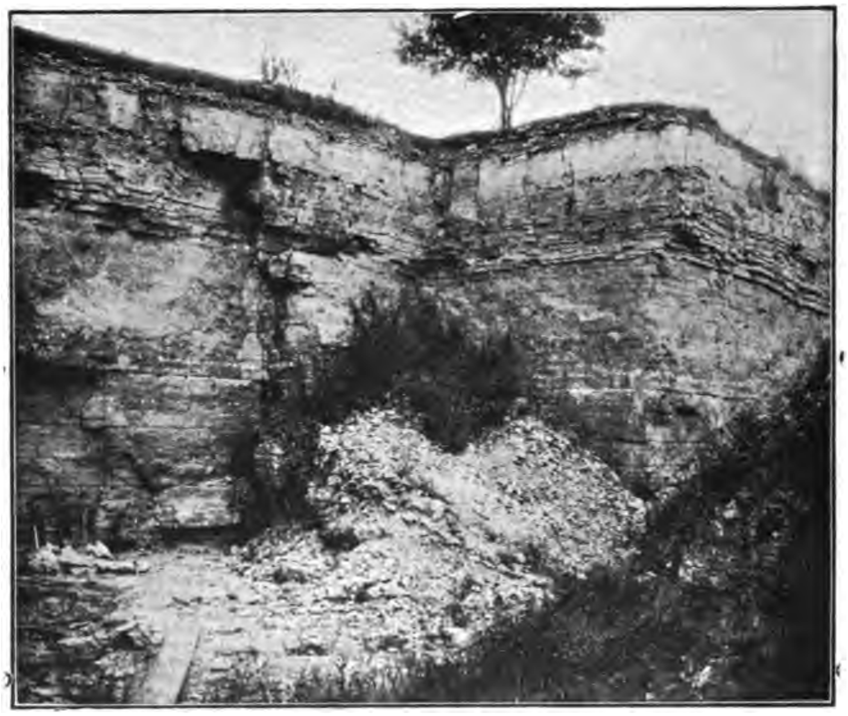

FIG. 16—Quarry in the Fort Atkinson limestone, at the town of Fort Atkinson, a few rods west of the old Fort.

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*Iowa Geological Survey, Vol. XVI, page 101.

the same limestone, on the east side of the fort, has been operated intermittently for some time and has furnished quite an amount of fairly good material. In the southwest part of Military township there are many quarries and natural exposures in the Fort Atkinson beds. The small quarry near the center of the southwest quarter of section 33, and that near Ossian in the northwest quarter of section 15, will be found noted with some detail in the part of the report on Winneshiek county which treats of the Fort Atkinson limestone.* On the north side of the Cresco-Calmar ridge the Fort Atkinson formation comes to the surface and is quarried near the center of the southwest quarter of section 27, Springfield township, and about sixty rods south of the northwest corner of section 5, Bloomfield. At the point last named the rock is yellower, softer, less crystalline than at Fort Atkinson. The rocks of this horizon become more earthy or shaly toward the northeast, and gradually lose the qualities of a pure dolomite which distinguish them at the type localities in Fort Atkinson and Clermont.

LIME.

While no lime is now manufactured in Winneshiek county, the materials for making a high grade product are not wanting. The upper two-thirds of the Oneota is particularly well suited for this purpose. This is a hard, granular, crystalline dolomite of much the same character as the Galena limestone which is so successfully made into lime at Eagle Point, Dubuque. At Waterville in Allamakee county lime is made and shipped extensively, and the stone used is the Oneota, the same stone that is so well developed at Highlandville and Canoe, and along the river below Freeport, in Winneshiek county. The non-dolomitic Galena formation in Winneshiek would make an excellent lime if it were used soon after it is burned, but it will not keep as well as lime made from the Oneota dolomite. It is liable to deteriorate by becoming air slaked if kept in stock for even a comparatively short time, and, if in this condition it is used for mortar, it is easily crumbled and washed out of the joints. The greater part of the Niagara limestone should make a good grade of lime. There is nothing in the Devonian that can be recommended for lime making, unless it may be the small amount of the lithographic phase in section 7 of Orleans township.

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* Iowa Geological Survey, Vol. XVI, pages 107, 108.

The Niagara.

The Niagara limestone, as developed in Iowa, comprises two stages, the Hopkinton, typically developed in Delaware and adjoining counties and formerly known as the Delaware stage, and the Gower, from Gower township in Cedar county, where this stage shows its typical development. The Hopkinton stage comprises a series of dolomites varying considerably in composition and structure. In general, they occur in heavy beds, with bedding planes obscure or wanting. At certain horizons and in certain localities, the beds are evidently laminated and even become flaggy in character. They range from hard, slightly vesicular, sub-crystalline, massive dolomites, to soft, earthy deposits. Certain horizons carry large quantities of chert. The Hopkinton attains its maximum development in Dubuque and adjoining counties. According to Professor Calvin* the following members of the Hopkinton can be recognized and he assigns their thickness as follows:

		FEET.
7.	Upper quarry beds	20
6.	Cerionites beds	25
5.	Pentamerus beds	50
4.	Syringopora beds	65
3.	Chert beds	25
2.	Lower quarry beds	20
1.	Basal beds	15
	Total	220

Number 5 is often sub-crystalline and essentially a pure dolomite and is of excellent quality for lime burning. It is used extensively in Jackson county.

The Gower includes two fairly distinct sub-stages, the LeClaire and the Anamosa.

The latter consists typically of soft, laminated, light buff to yellow dolomite in thin to medium heavy beds which are often practically parallel and nearly horizontal. Texturally the beds are porous, often highly vesicular, and usually present a rather dull and earthy luster. The layers are divided by occasional vertical joints.

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*Geology of Dubuque county, page 459.

The LeClaire beds on the other hand, comprise a hard, bluish gray to a grayish yellow, sub-crystalline dolomite. The prevailing color above the ground water level is some shade of yellow or buff. Texturally, while the LeClaire is usually sub-crystalline, it is generally vesicular and presents a decidedly rough appearance on a freshly fractured surface. It is sometimes brecciated or conglomeratic. Structurally, the LeClaire occurs in mounds and presents a very uneven surface which is filled by the even beds of the Anamosa. It sometimes appears to be massive, the bedding planes being scarcely recognized; at other times the bedding planes are apparent but are highly inclined; in still others, the beds are evidently laminated and nearly horizontal. The LeClaire, when typically developed, is an essentially pure dolomite and excellently adapted for the manufacture of a superior grade of lime and is so utilized at a number of points in Iowa and Illinois; notably, Cedar Valley, Sugar Creek and Viola in Iowa, and Port Byron in Illinois; while the Anamosa beds are especially prized as a dimension stone on account of their unusual uniformity in bedding, composition, texture and state of induration. More than three-fourths of the bridge and dimension stone of the state is derived from these beds. The leading quarries are located at Cedar Valley, Stone City, LeClaire and Mt. Vernon.

BREMER COUNTY.

The Niagara limestone is known to appear at the surface at but few points in Bremer county. The most important section appears along Baskin creek in the southeast quarter of section 17, range XIII west, township 91 north. The beds which may be seen in this quarter are as follows:

		FEET.
3.	Limestone, brecciated; composed of sharp angular fragments of a drab, laminated limestone of lithographic fineness of grain, in a gray matrix..	1
2.	Sandstone, filled with small angular fragments of white chert, in two or three layers, apparently conformable with 1......	½
1.	Dolomite, light buff, sub-crystalline, vesicular, with cavities up to eight inches in diameter; in heavy, irregular, rough-faced beds up to two feet thick..............................	13

The lower beds were quarried formerly and used in the manufacture of lime of excellent quality.

Similar, but less extensive sections occur in section 20 of the same township and in section 36 in Douglass township, three and one-half miles west of Tripoli. An analysis of the last mentioned occurrence shows its true dolomitic character, and is given below:

Silica	1.53
Iron oxide	0.48
Calcium carbonate	54.32
Magnesium carbonate	43.41
Combined water	0.26

None of the outcrops mentioned have been utilized to any extent commercially. All are located remote from towns and railways and notwithstanding their excellent quality for lime, and the fact that but little stripping is required, it is not probable that they will be important in the quarry industry for some time to come.

BUCHANAN COUNTY.

The Niagara limestone occupies a triangular area in the northeast one-third of the county. Outcrops appear along Otter creek in Hazelton township, and in Buffalo and Madison townships. The usual type exposed is the coarse, granular dolomite. Near Hazelton, in section 2 of Hazelton township, the coarse dolomite passes beneath fine-grained non-dolomitized limestone, varying in color from light drab to blue. Small openings have been made in all of the above areas but little stone has been taken out.

CEDAR COUNTY.*

Cedar ranks among the first counties of the state in the value of the yearly output of building stone, a pre-eminence due chiefly to the quarries at Cedar Valley. Formerly Lime City was an important producer, but at the present time, it contributes but little to swell the county total. Building stone of excellent quality is found widely distributed over the county, and while the small quarries which have been opened in almost every town-

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* Professor Norton's excellent write up on Building Stone in his report on the Geology of Cedar county has been revised and used almost in its entirety.

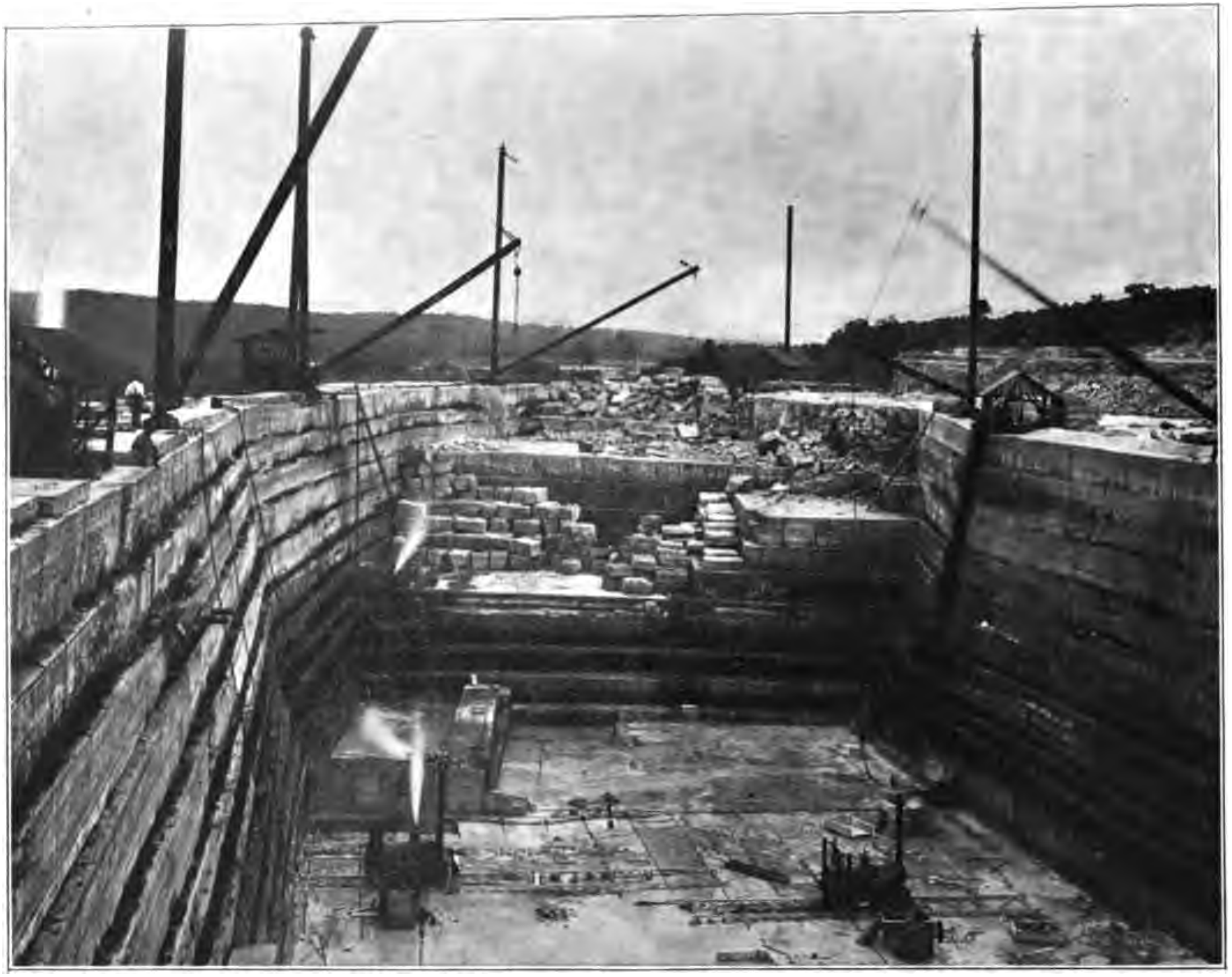

PLATE XXXV—Main pit of Bealer Quarry showing channelers in foreground. Cedar Valley, Cedar county, Iowa.

ship do not greatly add to the large amount contributed by the Cedar Valley district, yet their value and convenience to the rural districts and neighboring towns is greater than mere statistics could show. There is hardly a section in the county where a farmer or townsman can not get a load of cheap good stone within easy hauling distance. Thus in Pioneer township there are quarries at Peet's mill and elsewhere on Clear creek; in Cedar township at Cedar Bluff and two and one-half miles north of that village; in Gower township at Cedar Valley and Plato; in Center at several quarries south of Tipton; in Rochester along Rock creek; in Iowa near Atalissa; in Sugar Creek at Lime City and a number of quarries north of that village; in Springfield southwest of Lowden; in Massilon along the Wapsipinicon, and in Dayton township near Clarence. Nearly all of the building stone quarried in the county is furnished by the Gower stage of the Silurian, the only exception being that of the Devonian quarries in Iowa township near the Muscatine county line. The good qualities of the Anamosa phase of the Gower limestone have long been recognized and have frequently been set forth in the county reports on the counties of eastern Iowa. Its even and smooth bedding, its uniform grain, its comparative softness in working with saw and chisel when fresh from the quarry, and its hardness when recementation has taken place on drying, its obduracy to all chemical agencies of rock decay, and its resistance to frost, its pleasing color and the absence of any injurious minerals which might weaken or strain the stone or impair its ease of working, all these characteristics contribute to make the Anamosa one of the best building stones of the west.

Bealer Quarries.—In value of output, and perfection and cost of machinery, these quarries are the most noteworthy in Iowa and are among the largest of the Mississippi valley. They are located some six miles southwest of Tipton on the right bank of the Cedar. The village which has sprung up about them is called Cedar Valley, and a spur connects with the Cedar Rapids-Clinton line of the Chicago, Rock Island and Pacific railroad, near Plato, about two miles northwest. The sequence of beds is as follows:

BEALER'S QUARRY, CEDAR VALLEY.

		FEET.
9.	Limestone, buff, magnesian, very soft, Coggan stage	14
8.	Limestone, weathering into chipstone, in layers up to six inches	1¼
7.	Limestone, light gray; rough, massive, very vesicular	3
6.	Limestone, fragmental, argillaceous	1
5.	Seam of blue agillaceous material extending for] 180 feet along quarry face	0-2
4.	Limestone in thin spalls, hard, dense, "flinty"	5¼
3.	Limestone, hard, rough, buff, crystalline, highly vesicular, with moulds of spire-bearing brachiopods, the spires often remaining in casts	5
2.	Limestone in layers from two to eight inches, laminated	4
1.	Limestone, light buff, granular; lustre dull, homogeneous in grain, slightly vesicular, destitute of silica in any form, fracture even, soft when first quarried, rapidly hardening on drying, bedding planes horizontal, even and comparatively distant, laminated, joints distant, master joints running south-southeast. All quarried for building stone, together with Nos. 2-8, Gower stage	94

The quarries were opened nearly a quarter of a century since by Mr. E. J. C. Bealer, who, as a practical bridge architect, saw the great value of the stone at this point for bridge piers and all heavy masonry. The chief quarry now in operation was opened some years ago, and no expense has been spared to equip it with modern and effective machinery. A levee costing $20,000 has been built along the river front for protection against floods. Railway tracks in the quarries are so built that the force of gravitation is utilized to the utmost and no locomotive engines are required to make up the train of loaded cars which in busy seasons is sent out daily. The stripping of the quarry, consisting of twenty-five feet of soft silt known as loess, and less than ten feet of pebbly glacial clay, is cheaply and expeditiously handled hydraulically by means of a high duty steam pump and suitable pipes and hose. In quarrying the stone there are employed one single and three double steam channellers and several steam drills. The plant is well equipped with boilers and engines of sufficient capacity to furnish an abundance of power to operate the channellers, drills, pumps, machine shop equipment, crusher plants and numerous derricks. A large machine shop, well equipped for repairing and rebuilding the tools and machinery of the plant completes the equipment.

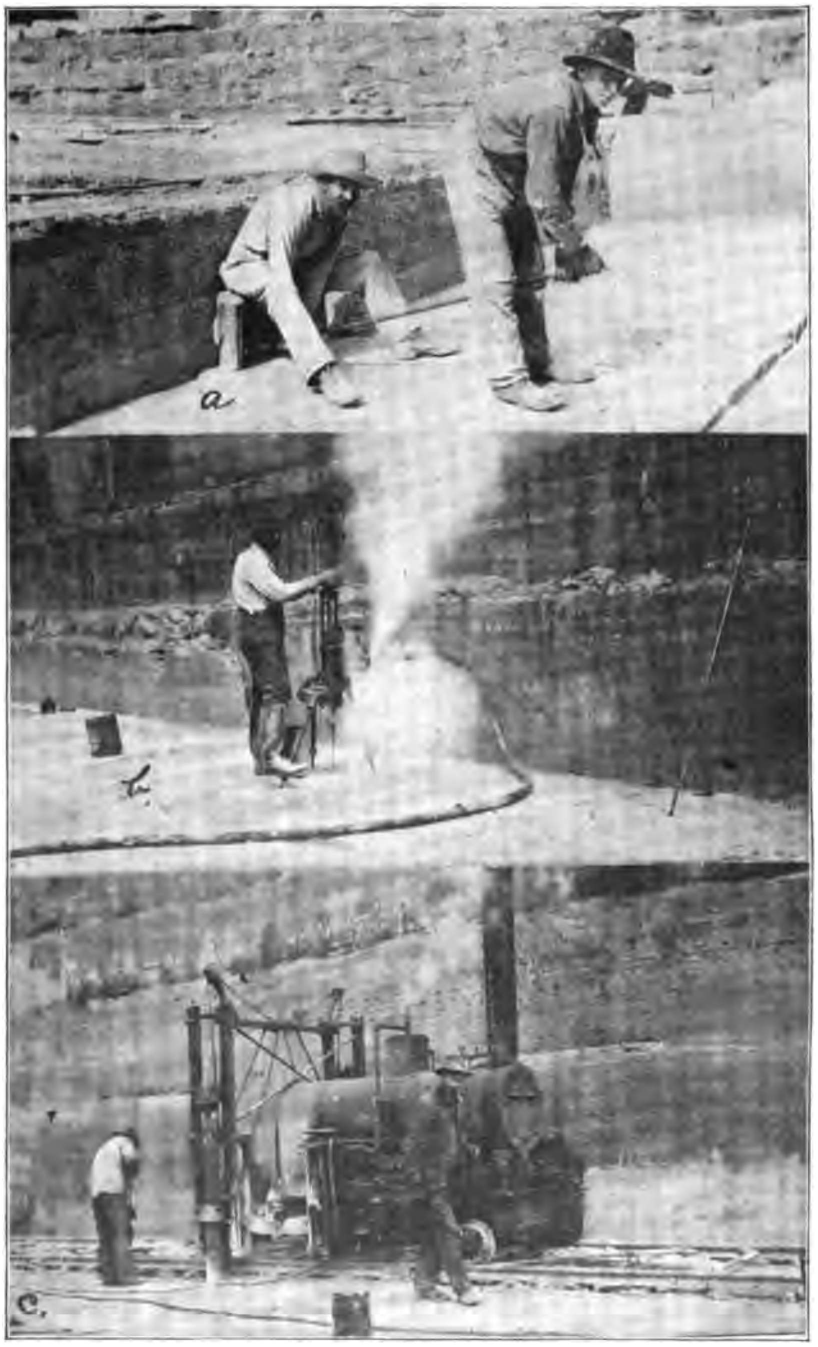

Plate XXXVI—Quarry methods in vogue at the Bealer Quarry.
a. Hand gadding.
b. Steam drill, a common type of rock drill.
c. Double channeler.

The output consists chiefly of bridge stone of three grades. The proprietor contracts for completed bridge piers and has a large force employed in their construction. Dressed dimension stone is cut in the yards and crushed stone, rip-rap, rubble and curb stone are included in the products of the quarry.

The quarries were opened in natural ledges fronting the river in the face of the bluffs, rising about 120 feet above the stream. These ledges have been quarried away over an area of several acres, and on the platform thus formed an extensive pit has been sunk to a depth of sixty feet below the level of water in the river, and another of like dimensions has recently been opened. The lower ninety-four feet is used for bridge and dimension stone, the stone becoming of finer grain and better quality, it is said, with increasing depth, to the present quarry floor. Above this lies a ledge of twenty-two feet thick used only for rip-rap, rubble, railway ballast, and macadam for which it is admirably adapted. It includes hard, fine-grained spalls, a four-foot layer of hard, highly vesicular, crystalline limestone, and four feet of laminated limestone in layers from two to eight inches thick. On this ledge rests a bed of about twelve feet of soft, earthy limestone, called the Coggan, wholly worthless for any industrial purpose, and constituting a part of the stripping.

The quarry stone belongs to the Gower stage of the Niagara, according to Norton. It consists of laminated, light buff, granular, even bedded dolomite which withstands chemical decay and mechanical disintegration remarkably well. Open bedding planes are so few that they are found to be practically impervious, a fact markedly at variance with similar beds in Anamosa and Stone City in Jones county. The chemical composition of the rock was found to be as follows:

BUILDING STONE QUARRY, LIME CITY.

Calcium carbonate ($CaCO_3$)	55.3
Magnesium carbonate ($MgCO_3$)	43.0
Ferric and aluminum oxides (Fe_2O_3 and Al_2O_3)	1.4
Silica (SiO_2)	0.6
	100.3

BUILDING STONE, BEALER'S QUARRY, CEDAR VALLEY.

Calcium carbonate ($CaCO_3$)	56.4
Magnesium carbonate ($MgCO_3$)	42.6
Ferric and aluminum oxides (Fe_2O_3 and Al_2O_3)	0.7
Silica (SiO_2)	0.4
	100.1

The rock, however, is laminated throughout and may be split along these planes to layers one foot in thickness without difficulty, and in places to eight and nine inches. On natural outcrops adjacent, long-weathered surfaces often show close lines of lamination, but these are strongly coherent, beyond the usual in this formation, and permit the quarrying of permanently solid blocks of as great thickness as called for. The common size of the blocks raised from the lower part of the quarry is six and one-half feet long and three and one-quarter feet wide and thick, weighing each something more than four tons.

In some of the outcrops of the Anamosa phase of the Gower stage, there are found, especially toward the summit, thin layers or laminæ of a compact, drab, fine-grained limestone, called by workmen "flint" on account of its hardness, brittleness, and fracture. Such seams are a direct injury; under the weather they break into small rhombic chip-stone. Since their coefficient of expansion is different from that of the adjoining layers, they tend to form in time a horizontal cleavage of the block of which they form a part. At Bealer's quarry these seams are practically absent, and the stone free from this element of weakness as well as of all deleterious accessories, can be strongly recommended as of the highest durability.

Cedar Bluff.—Immediately above the bridge at this village, a ledge of Anamosa stone has been quarried to some extent for local supply. The face of the ledge is here some thirty-five feet. The upper seven or eight feet are weathered to thin spalls. In the middle lies a stratum of seven feet of fine-grained, light yellow limestone of pure Anamosa type. Below this the stone shows an alternation of harder and softer laminæ, the harder being of finer grain and more brittle. The best building stones are said to be taken from the bed of the river at the base of the ledge.

Below the village the same formation outcrops on both sides of the river, in ledges up to fifty feet in height, showing the same granular laminated limestone, horizontally bedded in even courses, weathering in places to thin calcareous plates, but for the most part standing in undivided layers up to two feet in thickness.

McLeod's Quarry, southwest quarter of section 12, township 82 north, range I west.—On the left bank of the Wapsipinicon, less than one-half mile below Massilon, this quarry shows a face of twenty-five feet of vesicular, semicrystalline limestone, the upper fifteen feet massive or obscurely bedded, the lower ten feet in rough layers from eighteen to thirty inches thick, all buff in color, and sparingly fossiliferous. Just below the village on the right bank of the stream, the same layers form a picturesque ledge about thirty feet high.

Frink's Quarry, northwest quarter of southeast quarter of section 14, township 82 north, range II west.—The following section is here shown:

		FEET.
4.	Limestone, rough, in layers from one-half to one foot thick, weathered	4
3.	Limestone, in eight inch layers	2
2.	Limestone, exceedingly rough, crystalline, deeply pitted with rounded cavities up to five inches in diameter	2
1.	To creek level, not exposed	13

The layers here form a gentle syncline dipping 2° north at the south end and 6° south at the north end.

Burrough's Quarry, southwest quarter of section 22, township 80 north, range III west.—The Gower is here quarried on a small scale on the left bank of Rock run. For eight feet above the creek, a very fair granular building stone lies in layers from seven to eighteen inches thick, weathering superficially to spalls two to four inches thick. The dip to the southeast is perceptible. An adjacent ledge reaching a height of twenty feet above water level is composed of laminated limestone, hard, gray and crystalline. A few rods away an old pot kiln attests the possibilities of the stone as a lime maker. Here a layer identical with No. 4 of Whann's quarry is found above the limerock. Across the creek and down the stream on the same farm, about fifty feet of this hard, crystalline, laminated limestone is displayed in overhanging ledges and hillside outcrops. Toward the base the rock weathers to thin spalls, but above the laminæ are coherent and the cliff breaks down in immense blocks. About fifteen feet above the limestone a few fragments of yellow sandstone were seen in a shallow ravine, but no distinct outcrop was found. All the limestone in this section resembles the Anamosa stone in its lamination and in its horizontal or nearly horizontal bedding. Nowhere is it disturbed, tilted, or conglomeratic, as is so commonly the case with the LeClaire. And yet in their hardness, color, and crystalline texture, these beds on Rocky run are distinctly of the LeClaire type.

Wallick's Quarry, east half of section 16, township 81 north, range IV west.—Two and one-half miles north of Cedar Bluff the Anamosa phase is quarried for local uses. The rock rises to the surface in the low hills, so that no stripping, except of weathered spalls, is necessary. The rock is of the ordinary phase of the finely laminated, fine-grained, light buff building stone of the Gower. It is in thin layers, dipping 11° SE., and shows a face of twenty feet.

Hecht's Quarry, northeast quarter of northeast quarter of section 14, township 82 north, range II west.—The following section is seen at Hecht's quarry:

		FEET.
3.	Limestone, spalls, irregularly shaped chipstone, buff, resembling conglomerate of harder centres with matrix of limestone meal...	4
2.	Limestone, rough, semi-crystalline, cores gray, weathering to buff..	1
1.	Limestone, for the most part evenly bedded, buff or gray, thickness of layers from above downward in inches: 8, 18, 10, 15, 19, 24, 12, 18, 18. At west end a dip of 3° W.; in center slightly S.; at east end a perceptible dip SW........	11⅚

Cary's Quarry, southwest quarter of section 13, township 80 north, range III west.—About two and three-fourths miles southwest of Tipton, two quarries have been opened on Rock creek. Mr. M. C. Cary here quarries a face of fifteen feet in layers mostly of the thickness of flagging, but some reaching nine inches. At the west end of the quarry, the stone is hard and crystalline, of the LeClaire phase, in layers six inches thick and upward and dipping 12° SSE. Two rods east this has passed into the Anamosa phase, but slightly harder and more crystalline than typical, dipping 3° E., the juncture being now concealed.

Twenty-five rods southwest of this section a small quarry has been opened showing a mound of hard limerock at the north end, and, the juncture again being obscured, at the south Anamosa stone, some layers being soft and granular, and others harder and more compact. The layers here run from one and two inches to nine and twelve, and dip from 30° WNW. to 38° NNW.

Whann's Quarry, northeast quarter of northwest quarter of section 14, township 80 north, range III west:

		FEET.
5.	Limestone, light buff, hard, fine-grained, luster earthy, resembles Bertram beds of Linn county	2
4.	Limestone, buff, softer, with numerous branching vertical tubes one to two mm. in diameter	1
3.	Limestone, hard, gray, crystalline	1½
2.	Limestone, buff, more or less vesicular, in layers from 8 to 30 inches thick, with bands of harder crystalline gray rock.	5
1.	Limestone in layers as above, buff, granular, laminated.	6½

The dip here is a gentle one to the southwest. A few rods up stream the ledge is seen to form a low syncline.

LIME.

Rock of the highest excellence for the manufacture of lime is as broadly distributed over the county as is good building stone. This is due to the many areas where the Gower limestone is exposed by erosion, and to its rapid alternation at the same horizon between its two lithological phases. At no great distance from the quarries of the granular, evenly bedded Anamosa stone, there will be found outcrops of the crystalline, massive or obliquely bedded dolomite, which takes its name from LeClaire, the town in Scott county where its typical features were seen and described by Hall nearly fifty years ago. Thus at Lime City and at Cedar Valley, lime and building stone quarries are in close proximity. It is to these two places that the manufacture of lime is at present restricted. This is not due to any special advantage in the quality of their limerock over that of other localities in the county too numerous for mention, but to the facility with which the rock can be handled and the product placed on the market. In almost all portions of the county the explorer of outcrops of the country rock finds the white heaps of half burned lime and the ruined walls left to show the place of pot kilns. Owing to the increasing scarcity of wood and introduction of the clay limes from Missouri and the reduced price of Portland cement, the lime industry has become almost extinct.

The upper beds of the Silurian furnish a limerock of the highest degree of excellence. It is from them that some of the largest kilns in Ohio, Wisconsin and Illinois, as well as Iowa, draw their supply. The lime burned in Cedar county is identical with that of the well known kilns at Racine and Port Byron. Its pre-eminence depends upon its chemical and physical qualities. It is notably free from silica in all its forms and from argillaceous or ferruginous impurities. The large per cent of carbonate of magnesia present makes it a cool lime, slow to slack, slow to set. The hardness and durability of mortars made from this lime approach those of cement. Buildings are seen in which it was employed, where, after thirty-five years of weathering, the joints seem as fresh as when struck. Wholly minor advantages are the brittleness of the rock, which aids in its breaking to suitable dimensions for the kiln, and its vesicularity, which gives more ready access to heat in burning and to water in slaking.

The purity of the Gower dolomite is demonstrated in the following analysis made in the chemical laboratory of Cornell College under the supervision of Dr. Nicholas Knight:

Ledge on Rock Creek, southeast quarter of the southwest quarter of section 23, township 80 north, range III west:

Calcium carbonate ($CaCO_3$)	55.76
Magnesium carbonate ($MgCO_3$)	43.85
Ferric oxide and aluminum oxide (Fe_2O_3 and Al_2O_3)	0.26
Silica (SiO_2)	0.12

The total impurities of this specimen of the dolomite used in lime making throughout the county are but little more than one-third of one per cent.

Lime City.—The quarries of this plant are situated on the right bank of Sugar creek, five miles northwest of Wilton, a spur of the Chicago, Rock Island and Pacific connecting them with

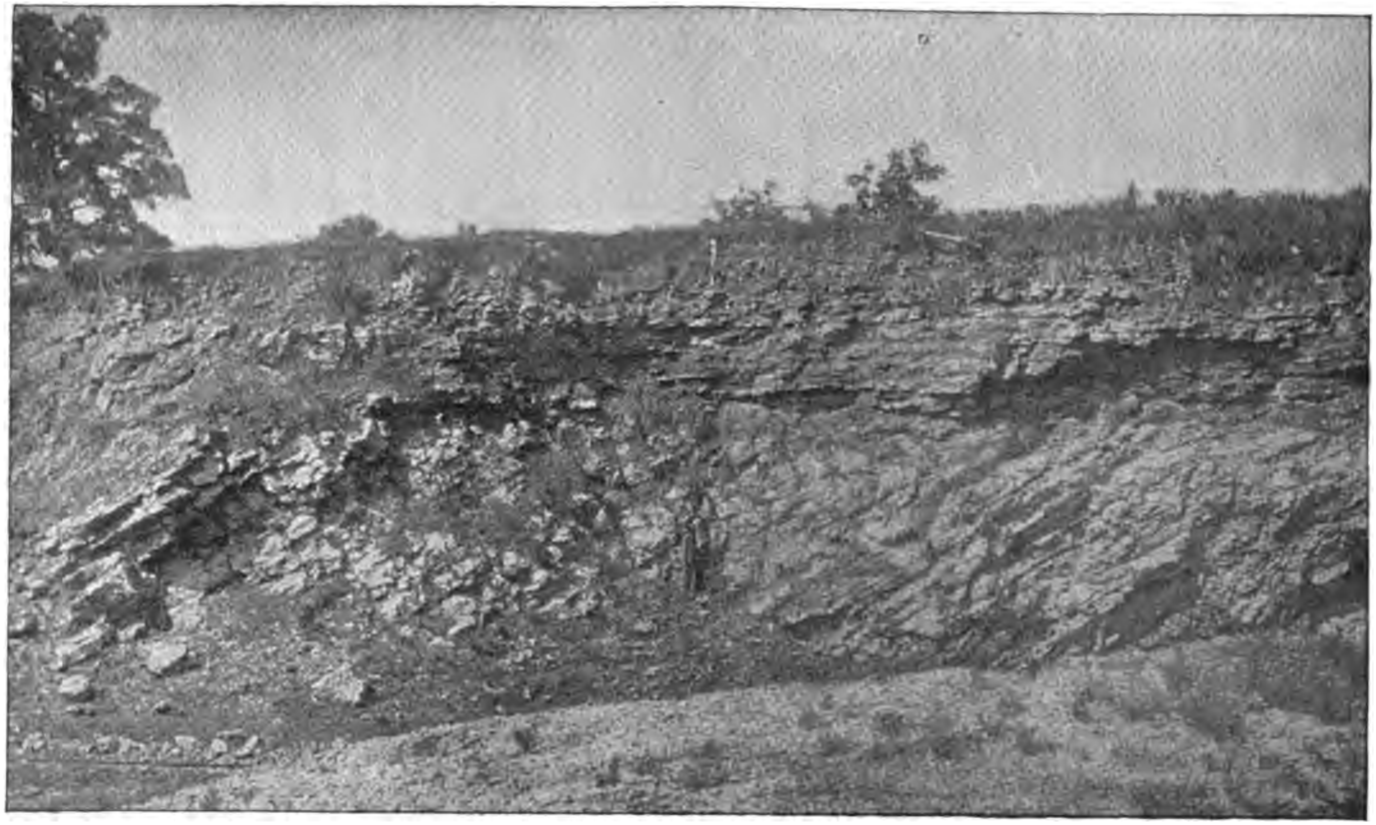

Plate XXXVII—Horizontal Coggan beds overlying the oblique-bedded LeClaire phase of the Gower limestone at Lime City. The lower beds are a remarkably pure dolomite and were formerly used in the manufacture of lime.

the main line at that junction. The rock is of the usual LeClaire facies. The following section may be taken as a fair average:

		FEET.
2.	Limestone, light buff, non-laminated, soft, earthy, with a strong odor of petroleum when struck with the hammer; in layers from six to twelve inches in thickness, cherty, nodules up to a foot in diameter	18
1.	Limestone, dolomitic, sub-crystalline, hard, massive; beds highly inclined; readily separated from beds which are horizontal	25

Dynamite was used in blasting and the stone was sent to the kilns by a tram running on a trestle. Four patent draw kilns were used and the lime could be loaded from the sheds directly on the cars. Some years since petroleum was used as fuel in one of the kilns, but later only wood was employed for calcination. The region about Sugar creek is forested, and wood was obtained at moderate expense. The output found ready market along the lines of the Chicago, Rock Island and Pacific Railway in Iowa and the states west. The amount of stripping is very slight. The beds of the Coggan, which overlie the limerock, are shipped for riprap and ballast, being wholly unavailable for lime or building stone. No lime has been produced here for some years and the plant is dismantled.

Cedar Valley.—The lime plant at Cedar Valley consists of three patent draw-kilns, each with a capacity of 120 barrels, and the usual storage and cooper sheds. Of the quarry face of sixty feet, scarcely any is unavailable for lime, and the expense of stripping is inconsiderable. The rock is economically handled, and the lime is loaded on the cars of the Chicago, Rock Island and Pacific Railway. It has found a wide market over Iowa and the adjacent states to the west. Wood is employed as fuel and is brought in from the heavily wooded hills of the Kansan upland on both sides of the river.

CLAYTON COUNTY.

The Niagara limestone covers an extensive area in the southern portion of the county, an irregular area on the divide between the Volga and Turkey rivers and small outliers in Grand Meadow and Marion townships. A large number of outcrops are available along the numerous stream ways. Quarries have been opened near Gunder and Strawberry Point. An extensive quarry is opened just across the line in Fayette county. The beds developed are similar to those available in Clayton county. The Niagara beds are somewhat variable but consist generally of a buff, heavy bedded dolomite, the ledges varying from two to four or more feet in thickness. The Wilkes Williams quarry which is described later under the discussion of Fayette county may be accepted as representative for the northern outliers in Clayton county. In section 15, Cass township, about one mile north of Strawberry Point, the following quarry section may be observed:

		FEET.
2.	Dolomite, coarse-textured, buff, containing chert nodules, in ledges eighteen inches to three or four feet thick......	8-10
1.	Dolomite, light gray, almost white, finely crystalline, free from chert, in layers from four to eighteen inches and two and one-half feet in thickness. The thicker ledges can be split into any desired thickness along lamination planes. The rock is soft when first quarried and grows hard on exposure.................	6-8

Similar sections have been developed at other points in the neighborhood. The beds are some sixty to seventy feet above the base of the Niagara. They are almost white, fine-grained and rather soft when first quarried and attain a thickness of twenty to twenty-five feet.

LIME.

Clayton county has a wealth of raw material suitable for the manufacture of good lime. Kilns have been operated at various points in the county and materials from several horizons were used. At the present time only two kilns are operated, both being located at Guttenberg and both utilize the transition beds of the Galena-Platteville. A better grade of lime could be made from the fully dolomitized beds of the Oneota, Galena or Niagara. Only sufficient lime is produced to supply the local demand.

CLINTON COUNTY.

With the exception of a small area close to the Mississippi in Elk River and Spring Valley townships, which is underlain by the Maquoketa shales, the country rock of Clinton county belongs to the Niagara stage of the Silurian. There are said to be exposures of Niagara limestone in every township in the county, save one, Berlin township.

It is quarried particularly in the vicinity of Clinton, where considerable thicknesses of the limestone are exposed in the bluffs bordering the valley of the Mississippi. There are also many small openings from which stone is removed, that are scattered so universally over the county that it is scarcely possible to segregate them into districts. Next to the Clinton quarries, in the depth of strata exposed as well as in commercial importance, come, no doubt, the group of small quarries in the south tier of townships near the Wapsipinicon and in the neighborhood of Wheatland, Calamus, and Dewitt.

The Niagara consists typically of beds of dolomitic limestone and dolomite, varying in nature from fine-grained, yellow, thinly laminated and porous layers, to heavy beds as great as six feet in depth, of brown to bluish gray compact stone. Chert in bands and nodules occurs very commonly throughout the Niagara strata. As mentioned, the stone has been quarried at a number of localities in different parts of the county. The following characteristic sections will afford an idea of the quality of the rock, the succession of the beds and the extent and possibilities of the building stone industry. They are taken in the principal quarry districts.

Clinton quarries.—The Clinton City quarry is located at Fourth Avenue and Bluff Road. The usable strata here consist of an upper four to five feet of soft, thin-bedded stone which grades into a somewhat firmer gray to bluish rock below. All of the beds are porous and often cavernous on a small scale. There are six to eight feet of weathered dolomitic residue and a varying depth of loess overlying the quarry. The lower beds are being used in city street work.

The Thomas Purcell quarry is located at Eighth Avenue and Sixth Street. A face of fifteen feet is open, running nearly a block parallel to Eighth Avenue and consisting of strata similar to those described above. Below the upper five feet the beds are heavy; in some instances individual ledges are three feet thick.

The bottom stratum contains nodules of white chert. Further quarrying here is limited by the city improvements.

The Union Park quarry belonging to the Turner Society and worked by Henry Jessen is situated at the intersection of Union Street and Bluff Road. A maximum of thirty feet of the Niagara is exposed, covered by three to four feet of drift and ten to twenty feet of loess. The upper portions of the dolomitic beds are fissured and weathered in places to a residuum or "geest." The top beds are also soft and of an ocherous yellow color. The bottom ledges are denser, of a gray color and run one to three feet in thickness. Only the latter are solid enough for foundation or other important masonry work. The quarry is worked constantly, hand methods only being practiced. The heavy and increasing amount of stripping necessary to obtain these lower strata is a great handicap to extensive development.

The quarry of Thomas Carey on Fourth Street, near Lamb's, is the most extensive opening in Clinton. There is less of the worthless disintegrated material here above the solid ledges. Thirty-five to forty feet of usable stone have been opened up and a large amount taken out. The individual beds vary in thickness from a few inches to three feet and products of any desired dimensions are obtainable. Fifteen to twenty feet of loess are removed to reach the quarry beds. The output consists of foundation material and some dimension stone from the deepest beds, while the upper strata are crushed for road and concrete work. The quarry is equipped with a portable jaw crusher made by the Western Wheeled Scraper Company.

The dolomitic beds are exposed at other points near Clinton, especially to the north in the vicinity of Lyons and in many places in the hills to the west along small tributaries. At all points the surface layers are usually badly honeycombed by weathering and solution, and often nothing remains but a yellowish crumbling dolomitic sand or dolomitic clay residuum. It is therefore necessary to remove in most cases great quantities of the disintegrated portions to reach the deeper solid and more durable ledges. These surface materials are serviceable in the shape of crushed stone, although they are not of the best quality, even for this purpose.

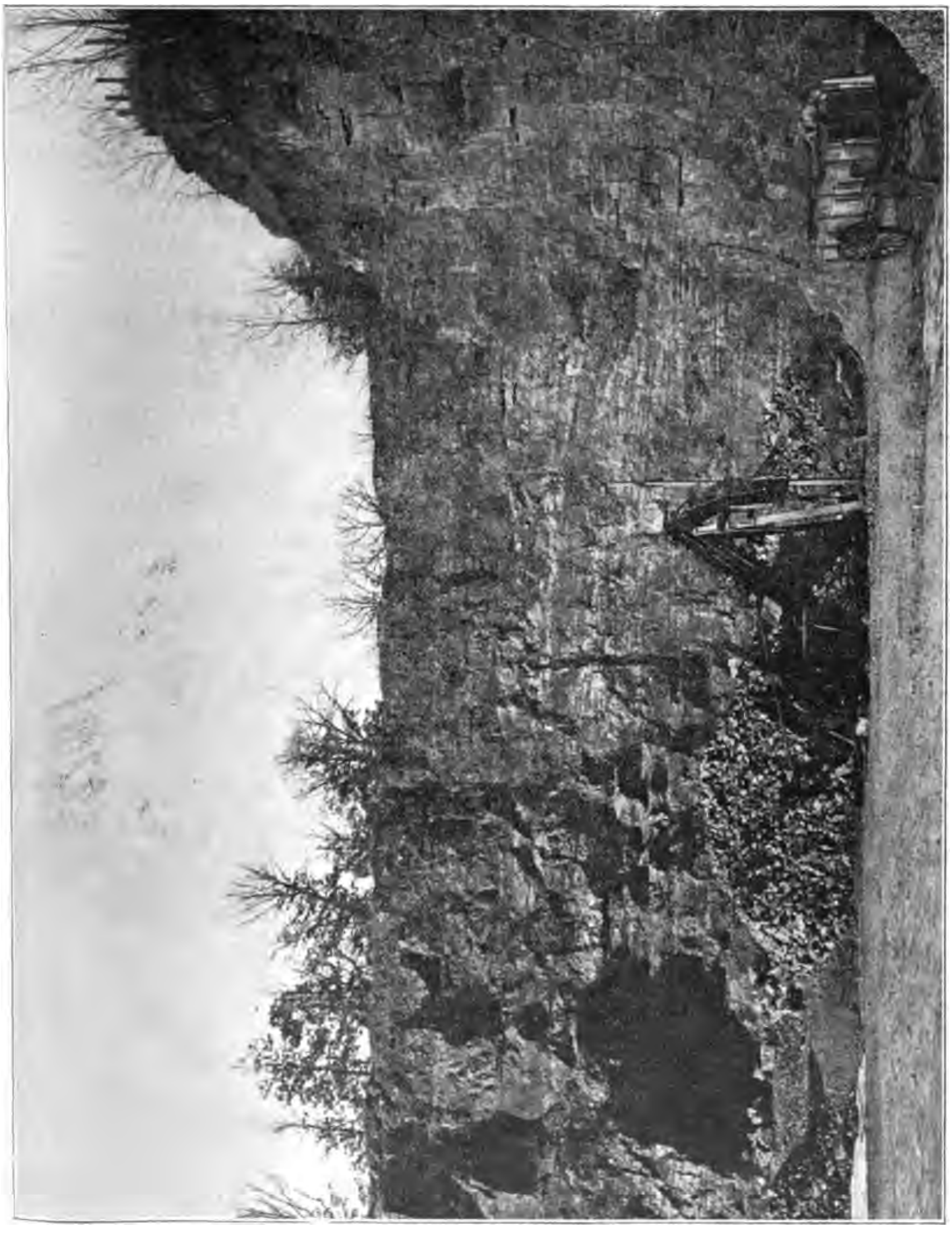

PLATE XXXVIII—Thomas Carey quarry section showing the general character of the Niagara beds of the region. The chert beds are rather prominent in the middle section. Clinton, Clinton county, Iowa.

The accompanying section is given as showing the general character of the lower Niagara beds to which the Clinton quarry rock belongs:*

		FEET.
6.	Drift	5
5.	Geest	3
4.	Porous and yellow, dolomitic limestone, irregularly bedded, full of small crevices lined with calcareous incrustations. This is known as "shell rock" among the quarrymen	40
3.	Finely granular, yellow, dolomitic limestone with numerous small cavities, often lined with a coating of crystalline calcite. Bands of chert occur at intervals of from two to four feet. Seven of these were each about five inches in thickness	30
2.	Buff-brown, dolomitic limestone of fine-grained texture, with many bands of chert, also scattered nodules of chert. The chert is most abundant below. Some of the chert bands have a thickness of one foot. These thicker bands occur above and the thinner lie below. Thirteen bands in all were counted. The lowermost, of which some were no more than an inch in thickness, lie close together	25
1.	Blue shale (Maquoketa)	15

In Orange township, the principal exposures are on Barber creek. On the land of A. A. Barber, in the southeast quarter of section 29, the following beds are in view in an old quarry:

		FEET.
4.	Soil	1
3.	Shattered and disturbed, yellow, thin bedded, limestone	9
2.	Very thinly laminated, yellow limestone, separating very readily along bedding planes into thin slabs of even a fraction of an inch in thickness	11
1.	The above rests on a floor which dips steeply to the north and consists of heavy, firmer ledges of weathered, porous limestone, some few feet of which have been worked.	

The top, No. 3, "slate," is being used as macadam and appears to give good service in this capacity on country roads.

Mrs. A. Smith has a small quarry south of Barber creek in the southwest quarter of the southeast quarter of section 29. Eight to ten feet of porous yellow limestone are exposed in beds from six inches to less than one inch in thickness. There is little drift or soil covering. The same stone crops out in the hills along both sides of Barber creek, southeastward, through sections 29 and 30. The strata are seldom horizontal but no uniform direction of dip was made out. In some instances the lack of horizontality is likely due to creep, but in general it seems to be the result of disturbances on a broader scale, which are indicated also by the shattering of the beds themselves.

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*Geology Clinton county, Iowa Geological Survey, Vol. XV, page 401.

Near the southwest corner of the northeast quarter of section 9, near Buena Vista, Olive township, F. C. Huehl has worked a quarry on the land of S. B. Walker. The beds are similar to those on Barber creek south of Grand Mound. They are less weathered and harder, more durable stone is obtained relatively near the surface and without much stripping.

In the vicinity of Big Rock post office in Spring Rock township the porous yellow dolomite is exposed in the cliffs along Rock run, and at numerous places to the south of the river in Scott county.

In Sharon township, stone has been quarried on the farm of Henry Kiel, one-half mile east of Lost Nation. The beds here are porous, uneven and cherty.

The quarry section given below is exposed one-fourth of a mile east of the center of section 15, Sharon township:*

		FEET.
10.	Drift	5
9.	Geest	4
8.	Fine-grained and laminated rock, breaking along the horizontal seams into slabs from one to three inches in thickness	4
7.	More coarse-grained and porous, evenly bedded, yellow dolomitic rock, without well marked lamination	3
6.	Fine-grained dolomitic limestone, in places with very distinct crystalline texture, and weathering into slabs about four inches in thickness	3
5.	Yellow rock with occasional pockets set with crystals of calcite	4
4.	A single layer of fine-grained, dolomitic rock	3
3.	Brownish, dolomitic limestone of compact texture, breaking much in quarrying, and having occasional crystals of calcite	3
2.	Laminated, fine-grained and compact, dolomitic limestone, breaking into layers one inch in thickness, occasionally bearing chert	1
1.	Solid and compact ledge of gray, dolomitic limestone, with some empty crevices lined with a thin coating of crystals of calcite	2

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*J. A. Udden, Iowa Geological Survey, Vol. XV, page 400.

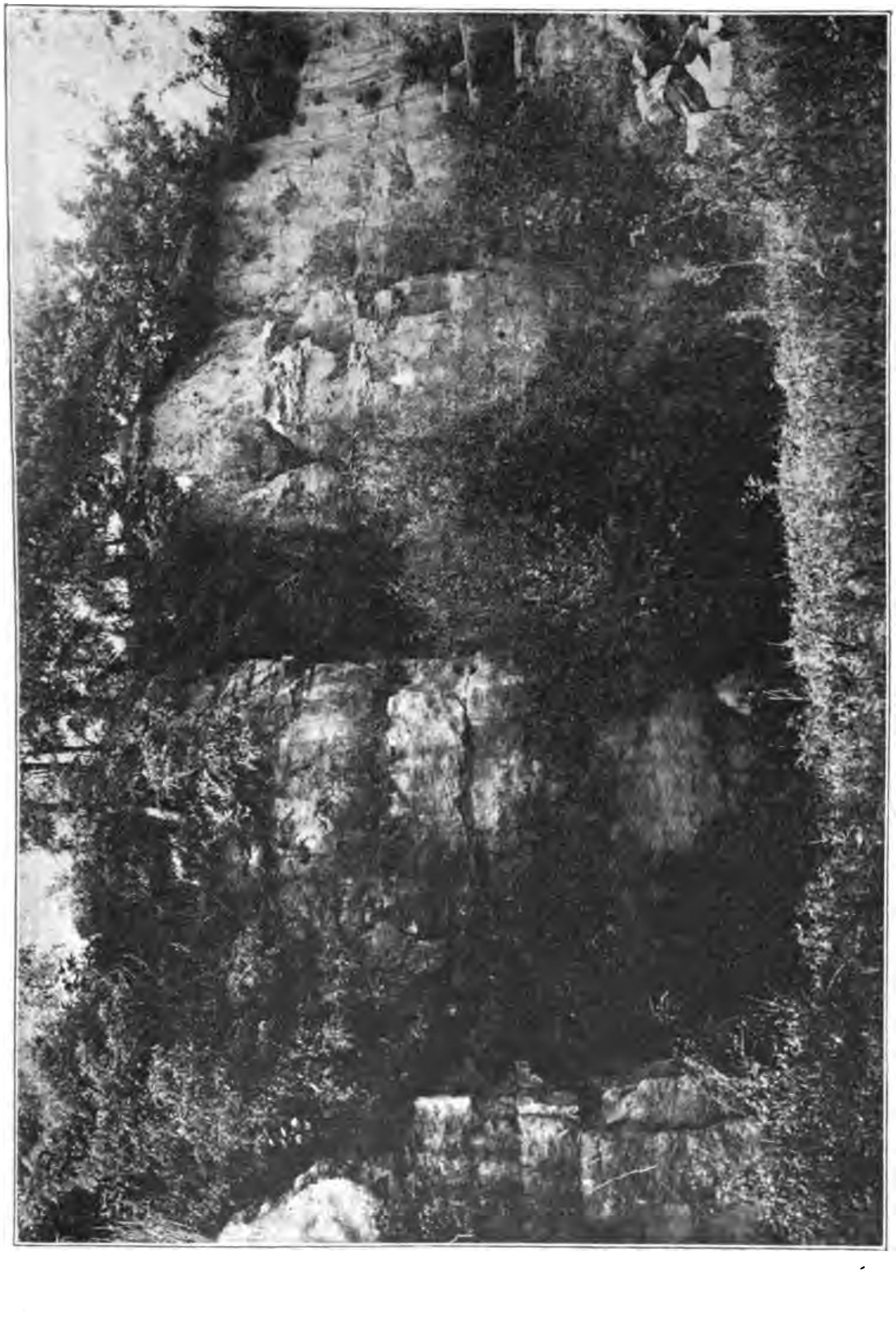

PLATE XXXIX—Old Randall quarry near Big Rock, Clinton county, Iowa, showing heavy Niagara beds.

DELAWARE COUNTY.

The Niagara limestone forms the country rock over nearly the entire county and furnishes an unlimited quantity of stone suitable for structural purposes, crushed stone and lime. Numerous outcrops appear along the principal rivers and most of their tributaries and these have been developed to meet the merely local demand. Quarries have been opened at a large number of points, especially in the northeastern half of the county. According to Calvin there are two horizons at which evenly bedded, easily quarried stone occurs, and the quality of the stone at both horizons is such as to place it among the best in Iowa. The lower stone horizon begins about thirty feet above the base of the Niagara limestone and has a thickness of more than thirty feet. The other horizon occurs near the top of the Delaware stage, above the Pentamerus beds, and has about the same thickness as the lower quarry-stone horizon.

The principal quarries of the lower horizon are located in Elk township. There are at least four in section 16, one in section 23, and two or three occur in section 2. All are worked more or less constantly during the summer season.

The Wilcox quarry is located on the southwest quarter of section 16, and is typical of all the others at this geological level. It presents a vertical face of about thirty feet. The beds range from three or four, to thirty-six inches in thickness. The heavier layers are toward the top of the exposure, and some of these contain numerous cherty concretions. Near the base of the quarry the stone lies in thinner layers and is free from chert. The quarry is capable of yielding good material for cut dimension stone, all kinds of ashlar work, rubble and heavy dimension stone for bridge piers. A great number of joints trending southwest-northeast cut vertically through the strata. The best material for cut stone lies about the middle of the quarry section. Here the beds are free from chert, and the surfaces of the individual layers are comparatively parallel planes. Near the base of the quarry the layers present uneven surfaces, the irregularities resembling the effects of wave action.

The Wilcox quarry is situated on the north side of a triangular ridge separating two converging valleys. Around the point of the hill, and almost opposite the exposure operated by Wilcox, another opening has been made in layers corresponding to those in the upper part of the Wilcox quarry. The stone is weathered at the top, and is overlain by dark brown residual clay, residual chert and a thin layer of loess. There are no signs of drift. If the Kansan drift was ever laid down in this locality it was entirely removed by erosion before the deposition of the loess. All the other quarries opened at this horizon show essentially the same details as those described.

Regularly bedded limestone, apparently the same as the beds worked, continue below the base of the Wilcox quarry for at least fifteen feet, and hence there is a total thickness of forty-five feet of beds that might be quarried. Between the quarry stone and the horizontally laminated beds at the base of the Niagara there is a rather gradual transition through strata intermediate in character. No fossils were noted either in the basal beds or in the quarry stone.

There are quarries at the same horizon in Bremen township. One of these is located south of the center of section 13, and there are two or three in section 26. A quarry in the northern part of section 26, furnishes good stone for rough masonry. The rock is granular, vesicular, much pitted by weathering where exposed, rather evenly-bedded; beds are horizontal and vary from a few inches to more than a foot in thickness. The pitted condition due to weathering is peculiar and distinguishes the rock of this locality from the equivalent beds on Elk creek. The quality is inferior when compared with stone from the Elk creek quarries. Another quarry in which the stone shows similar peculiarities of weathering occurs a short distance southwest of the center of section 26, Bremen township.

Beds of this lower quarry stone horizon, resembling those on Elk creek, are exposed at many points along the Little Turkey river and its branches in the northeastern part of Colony township.

The best exposures of the upper quarry horizon are seen in Union township, a few miles southwest of Hopkinton. The Merriam quarry, in the southeast quarter of section 23, has been worked longer than any of the rest, and may serve as a general illustration. The section is about as follows:

MERRIAM SECTION.

		FEET.
11.	Layers of limestone alternating with layers of chert each about three inches thick	2½
10.	Single layer, with embedded concretions of chert	2
9.	Three to six inch layers of limestone, alternating with two to three inch layers of broken chert	5
8.	Fair rock with little chert	1½
7.	Even-grained rock, cleavable	⅚
6.	Good quarry stone in several layers	3
5.	Compact layer with large, flat Pentamerus	2
4.	Lowest layer worked	⅚
3.	Vesicular ledges below base of quarry	3
2.	Cherty layers	4
1.	Cherty and vesicular layers down to talus	18

The Merriam quarry has from fifteen to twenty feet of excellent quarry stone. There are two or three other quarries worked at the same horizon in the same quarter section.

The Loop quarry is situated in the northwest quarter of section 25, township 87 north, range IV west, about one mile southeast of the Merriam quarry. This quarry has been worked for a number of years, and it is capable of furnishing a large amount of valuable building stone. The stone is fine-grained, homogeneous, easily worked and of good color. As the quarry is carried farther back into the hill, the aggregate thickness of the available stone will increase to twenty-five or thirty feet. The beds now exposed furnish excellent material for rubble, range courses and dimension stone up to ten inches in thickness.

Quarry stone belonging to the Merriam quarry horizon crops out at a number of points along a small ravine in the east half of section 17, South Fork township. The bedding seems to be thinner here than on the west side of the Maquoketa in Union township. Some of the beds, however, are ten inches in thickness; and quarries worked on the northeast quarter of section 17, and on the southeast quarter of the same section, have furnished a large amount of good building stone for local use. Another small opening at this same horizon was noted in section 14 of South Fork township.

There are several quarries in the upper building stone beds in Milo township. The largest are located in the eastern part of section 9, near the north end of the highlands, called in Calvin's report on Delaware county the Delhi plateau. The land on which the quarrying is done is nearly 200 feet higher than the Maquoketa river at the nearest point. The rock is here less magnesian than at other exposures in the county. A large proportion of it is bluish in color, and there are many large pockets of calcite. The bedding is quite regular, but the quality of the stone is not equal to that at the Merriam and Loop quarries farther south. A much better quality of stone is furnished by the Matthews quarry located near the center of section 4. The Matthews quarry has beds ranging from two inches up to two feet in thickness. The stone has a good color, rather fine texture, and may be used for the better grades of structural work.

In Delhi township the upper quarry stone is worked to some extent at Beal's quarry, in the town of Delhi. It is exposed and might be easily quarried, in the bluff south of Fleming's mills, in section 29, and there are a number of other exposures, though at rather inaccessible points, along the bluffs of the Maquoketa, in sections 29, 30, 33, 34 and 35. A small quarry capable of affording very excellent stone is opened on the northeast quarter of section 23.

The Pentamerus beds are usually massive and break on quarrying into shapeless pieces, but at a few points in the county they

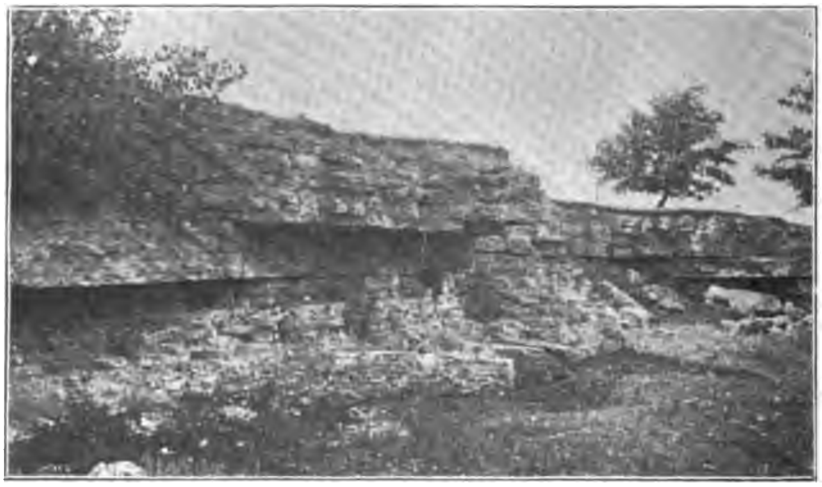

FIG. 17—Regularly bedded Pentamerus-bearing limestone in section 31, Bremen township one mile east of Earlville, Delaware county, Iowa.

lie in comparatively thin, even layers that may be quarried without difficulty, and yield stone suitable for a number of purposes. The position of the Pentamerus beds is between the two quarry stone horizons already described. A small quarry is worked in the Pentamerus horizon in the northwest quarter of section 3, Colony township. In the same township there is another quarry at this horizon near the center of section 27, and still another is worked in the southwest quarter of section 35. The last mentioned has been operated more extensively than the other two. The quarry face is about eight feet in height. The beds are somewhat shattered near the top. Chert is abundant as partings between the layers or as concretions embedded in them. The limestone is overlain by a very reddish brown, pebbly Kansan drift.

Some of the most important quarries worked in the Pentamerus beds are located in the southwest quarter of the northwest quarter of section 31, Bremen township. In one of these quarries there is an exposed section, thirteen feet in thickness, which shows:

		FEET.
2.	Coarse vesicular stone in heavy ledges, ledges varying from eight to thirty inches in thickness........................	8
1.	Evenly-bedded stone in layers two to six inches in thickness. Some of the layers contain *Pentamerus oblongus* with shells partly preserved. Stone is soft earthy dolomite, with some chert..	5

The massive beds of No. 2 contain Lyellia, Favosites and other corals. These thick ledges are undermined in taking out the thinner layers of No. 1, and great blocks left without support fall down on the floor of the quarry.

Some stone is obtained from this horizon near Sand Spring in South Fork township. Pentamerus limestone is used for foundations and bridge piers at Forestville in Richland township. Near the northwest corner of section 2, Milo township, there is a small quarry that with rather coarse, thin-bedded limestone, furnishes an unusual amount of chert.

LIME.

With an abundance of stone of first-class grade for lime burning, it is a little surprising to find that no lime is produced in

Delaware county. There are no kilns that are operated continuously or that attempt to do more than supply some temporary local demand. There are scores of localities where the Pentamerus and coral-bearing beds, lying between the two quarry stone horizons, are massive, crystalline and free from chert. In such case, if properly managed, they will produce a superior quality of lime. Remains of abandoned limekilns are found in almost every neighborhood where the Niagara limestone outcrops, but no kilns are in operation at the present time. There are half a dozen or more of these old kilns in the neighborhood of Hopkinton. No better lime was ever made anywhere than that which these kilns produced when they were operated. The raw material is abundant and easily obtained. What is lacking is capital, organization and efficient management. Dubuque lime, and other limes not one whit better than the home product, but made on a large scale by improved methods, are able to supplant the home product when made by the primitive appliances adopted by the pioneer settlers of the county.

DUBUQUE COUNTY.

The Niagara limestone covers the western portion of the county and has been quarried at several points. Two well defined quarry horizons have been developed, one near the base of the series between the fifteen feet of basal beds and the chert beds, and the other at the top of the Niagara series as they occur in Dubuque county. Each horizon comprises about twenty feet of good quarry stone, the lower beds being typically shown in the quarries about Farley, while the most important quarries in the upper beds have been opened near Cascade. The basal beds and beds between the lower and upper quarry beds, while suitable for rubble and crushed stone purposes, are not quarried extensively at any place in the county.

Typical sections of the lower beds may be seen in the quarry of Peter Milesi, east of Farley, and in the Arquitt quarry north of the same town. The Milesi quarry, located in the southwest quarter of section 8, Taylor township, on the Illinois Central railway, shows the following beds and layers:

MILESI SECTION.

		INCHES.
8.	Coarse-grained bridge stone	21
7.	Stone of medium grade	28
6.	Ledge of fine-grained stone, with some chert	24
5.	Stone similiar to number 6	14
4.	Fine-grained stone of good quality	4
3.	Stone of same quality as number 4	17
2.	Stone similar to 3 and 4	9
1.	Stone like 2, 3 and 4	26

The North Farley quarry, located on the Chicago Great Western railway, shows practically the same series but with slightly different thicknesses and other unimportant differences. The sequence is as follows:

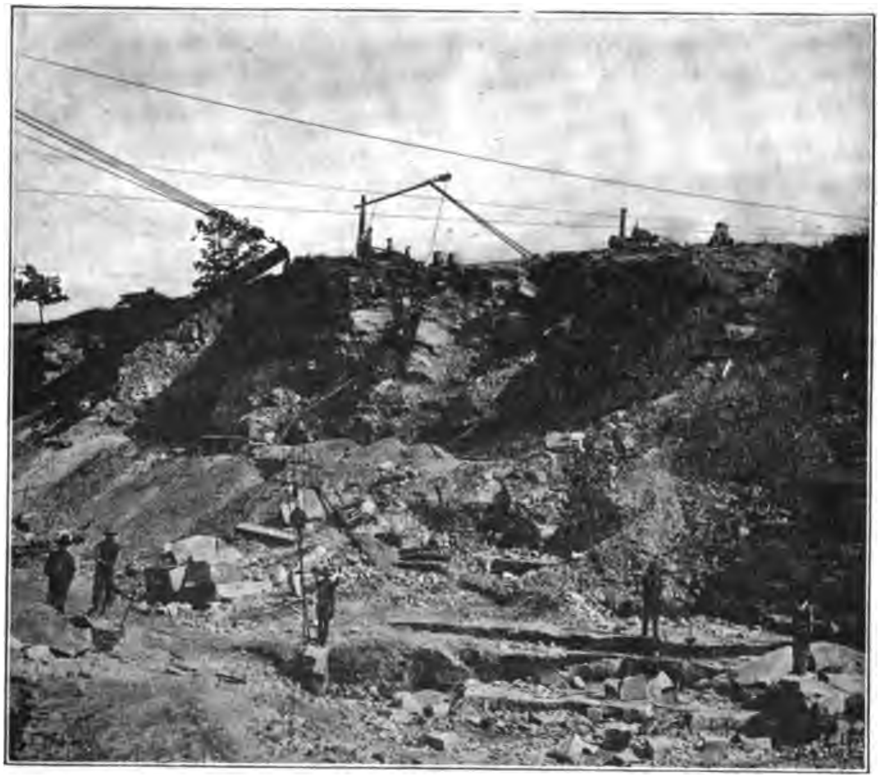

FIG. 18—Arquitt Bros. quarry, somewhat obscured by an excessive amount of talus. North Farley, Dubuque county, Iowa.

NORTH FARLEY QUARRY.

		INCHES.
9.	Thick course used for cellar rock and rip-rap	36
8.	Heavy course used for bridge rock	24
7.	Bridge rock	24
6.	Bridge rock	16
5.	Cherty layer, furnishes some good material	18
4.	Coarse, cherty in places, but sometimes furnishes very good stone	14
3.	Coarse with some chert, used for cellar walls	12
2.	Stone of excellent quality, easily sawed to requisite dimensions	16
1.	Bottom ledge of good quality, caps along certain planes, easily sawed	26

The beds quarried at each place are dolomitic limestones, light yellow to buff, fine-grained and finely laminated. The courses are separated by shaly partings and are soft and very easily worked. In the Arquitt quarry the stone is sawed and dressed by machinery and very closely resembles the Cedar Valley and Stone City stone. The lower quarry beds appear and are quarried farther east; small quarries have been opened on section 2, Taylor township, and section 36, Iowa township. At the former the Niagara-Maquoketa contact may be seen and the beds exposed are as follows:

		FEET.
5.	Chert beds consisting of coarse-grained dolomite in very uneven, thin layers, interbedded with a large amount of chert	4
4.	Lower quarry stone in courses varying from eight inches to two feet in thickness; stone light gray to cream color, rather fine-grained, the upper layers carrying more or less of chert	14
3.	Basal beds in heavy layers which are, however, capable of being split along lamination planes into relatively thin divisions	12
2.	Transition beds of Maquoketa	13
1.	Plastic shale of the Upper Maquoketa; not measured.	

The Iowa township quarry shows beds higher in the series and less good quarry rock than the Taylor township section.

About 165 feet of almost worthless material intervene between the lower quarry beds and the upper quarry beds. The rock which constitutes these upper beds is in even layers varying from three to ten inches in thickness, fine-grained, cream to light buff in color and affords an excellent quality of material for the less massive grades of building stone. The stone was used in building Saint Martin's church at Cascade. Numerous outcrops of the upper beds appear in White Water and Cascade townships. The beds intermediate between the upper and lower quarry beds are well shown in the cliffs near the southwest corner of section 32, White Water township. The sequence is as follows:

		FEET.
11.	Light-colored, fine-grained rock resembling the upper quarry beds	2
10.	Dolomite, soft, yellow, easily decomposed, Cerionites beds	4
9.	Dolomite, moderately hard, yellow	5
8.	Dolomite, soft, fine-grained, gray, Cerionites beds	15
7.	Dolomite, coarse, massive, standing in vertical cliffs; *Pentamerus oblongus* horizon	45
6.	Dolomite, hard, very compact, with many casts of Pentamerus, and some chert	5
5.	Soft, rapidly weathering, light gray beds, with *Pentamerus oblongus* and non-silicified corals	2
4.	Dolomite, moderately soft, weathering rapidly, containing the same corals found in number 3	7
3.	Hard, dark gray beds, with many colonies of *Favosites hisingeri*, *Halysites catenulatus*, *Syringopora tenella*, and *Heliolites interstinctus;* all the corals are silicified; a good lime-burning rock	8
2.	Dolomite, coarse, granular, light buff, weathering irregularly and showing definite bedding planes; silicified corals, as in number 3	20
1.	Slope to level of water in stream, rock not exposed	20

The intermediate beds have been quarried in this vicinity and also near Dyersville and other points in the county.

FAYETTE COUNTY.

The Hopkinton stage of the Niagara occupies a very irregular area over the north, east and south portions of the county. The larger streams of the area have cut entirely through the heavy beds of limestone and expose the Maquoketa shales, the undercutting of the softer beds tending to produce and maintain escarpments facing the streams. Numerous outcrops appear upon the entire area and quarrying on a small scale has been done at a number of points. The most important quarry in the county is located on the northeast quarter of section 24, Clermont township, and is owned and operated by Wilkes Williams. The beds exposed are as follows:

WILLIAMS QUARRY SECTION.

		FEET.
8.	Clay, reddish, largely residual, but containing occasional pebbles and small bowlders of greenstone and granite	3
7.	Dolomite, much decayed, yellow, containing very abundant nodules of chert; long exposed surfaces present numerous cavities from which chert masses have weathered; lamination planes irregular and imperfectly developed, indicated by bands of chert	14
6.	Dolomite, coarse-grained, yellow, containing a large amount of chert in the upper part	2
5.	Dolomite, heavy ledge, yellow in color and rather coarsely granular in texture, without chert	3½
4.	Dolomite, coarse-grained, yellow in color, containing no chert	1
3.	Dolomite, regular layer, rather fine-grained, without chert	1⅚
2.	Dolomite, yellow, resembling No. 1 in texture, two and one-half feet in thickness at the south end of the quarry, increasing to four feet in thickness at the north	4
1.	Dolomite, heavy ledge, homogeneous, fine-grained with no tendency to split along planes of lamination, and containing no fossils or chert nodules; increasing in thickness toward the north	4

The quarry is located near the Clayton-Fayette county line, and the beds which are being developed belong to an outlier of Niagara separated from the main body. Several other outliers similar in character appear in the immediate neighborhood. About twelve to fourteen feet of stone is utilized for various structural purposes and gives excellent satisfaction. Lack of transportation facilities greatly limits the capacity of the quarries, as the stone must be hauled to Clermont or Postville for shipment. Over the northern portion of the county the Hopkinton beds are remarkably pure. Near Auburn the beds are prevailingly a gray limestone, in layers two to six feet in thickness, somewhat vesicular and lamination planes not evident. The stone is very hard and brittle, breaking with a conchoidal to uneven fracture and in one direction about as readily as in another. Samples were collected and analyzed with the following results:

	1	2	3	4	5	6
Silica	49.60	0.68	11.95	33.82	7.55	18.31
Alumina	6.36	0.50	2.80	7.83	3.43	3.60
Iron oxide	6.25			1.92		
Lime carbonate	....	98.52	84.80	....	78.69	73.48
Lime	22.45	....	....	31.78	....	....
Magnesium carbonate	....	....	0.45	....	2.40	3.10
Magnesia	0.20	....	....	1.52	....	....
Soda	0.35	....	....	1.82	....	....
Potash	0.90	....	....	4.25	....	....
Moisture	....	....	....	....	....	0.08
Loss on ignition	13.56	....	....	15.60	6.90	....
Sulphur trioxide	0.37	....	....	1.62	0.84	1.52

L. G. Michael, analyst.

1. Maquoketa shale, Auburn Mills. Average samples.
2. Niagara limestones, Auburn Mills. Average samples.
3. Argillaceous limestone, near Clermont.
4. Shale near Clermont.
5. Natural cement rock near Clermont.
6. Shaly limestone near base of Maquoketa at Elgin.

Auburn Mills is an inland town and while both shale and limestone are exposed in unlimited quantities they are not available commercially at the present time.

Over the southern portion of the county the Niagara limestone is a rather coarse-grained, yellowish brown dolomite, and belongs much higher in the series than the beds exposed in the Williams quarry. In places it becomes arenaceous and usually carries large numbers of chert nodules. In the vicinity of West Union the material is often fine-grained, very hard, light gray limestone, containing a large amount of chert concretions. Near the northeast corner of section 22 in Union township, the following succession of beds is exposed:

WILLIAMS AND DAVIS QUARRY SECTION.

	FEET.
8. Limestone, impure, yellowish gray in color, and fine-grained; no chert	1½
7. Limestone, gray colored, very hard, in places showing a tendency to separate into layers eight, three, two, four and eight inches in thickness respectively; without fossils, and containing no chert	2
6. Limestone, much shattered, gray, containing a very large amount of chert in the form of nodules and irregular masses	1½

	FEET.
5. Limestone, dense, fine-grained, gray in color, without fossils, almost free from chert in the middle portion	1
4. Limestone, gray, consisting of layers two to four inches in thickness, which are separated from one another by bands of chert	4
3. Limestone, fine-grained, gray, in two layers one and one-third feet and one foot in thickness; containing much chert and separated by a chert seam	2⅓
2. Limestone, massive, containing a very large amount of chert in the form of bands and imbedded nodules	43⅓
1. Limestone, gray, cherty, in layers three to six inches in thickness	

Number 1 in the above section is believed to be the equivalent of the upper portion of number 7 in the Williams quarry. The beds here are not dolomitized save for a few feet near the top.

Small quarries have been opened at other points in Fairfield and Auburn townships to supply the local demand. Good natural outcrops are available at many other places.

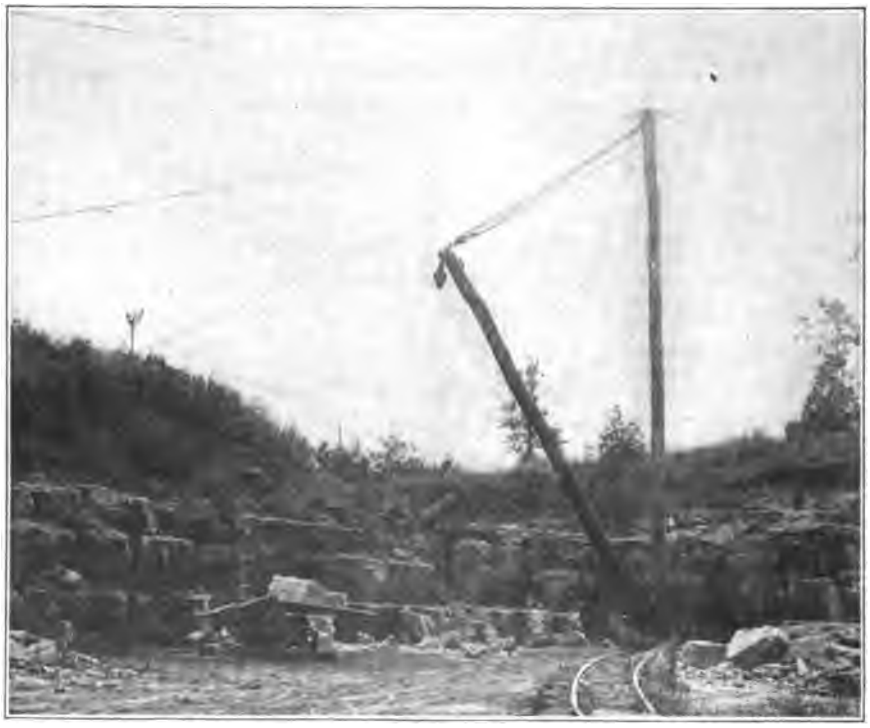

FIG. 19—Wilkes Williams quarry showing the rough, heavy bedded facies of the Niagara, section 22, Union township, Fayette county, Iowa.

JACKSON COUNTY.

The Niagara limestone immediately underlies the drift over more than five-sixths of the surface of the county and supplies the chief rock quarried, for both lime and structural purposes. All of the beds developed, with the exception of a small area in Brandon township, belong to the Hopkinton stage. They consist, for the most part, of very heavy layers of sub-crystalline dolomite ranging from two to eight feet in thickness and imperfectly stratified. The basal beds form an almost continuous outcrop along the Mississippi and appear in Van Buren and Fairfield townships. Good sections appear at numerous points along the principal streamways in the interior of the county. From this wealth of outcrops only a few quarry sections are given, however, sufficient to give the general features of the beds and indicate their availability. The Hopkinton is represented by a basal yellow dolomite, which is non-fossiliferous and free from chert. It ranges from four or five to ten or twelve feet in thickness. These layers are overlain by the chert beds, which consist of an earthy yellow dolomite, thinly bedded and interstratified with bands of chert, and attain a thickness of from eighteen to twenty feet. The chert beds are followed by the massive, granular dolomite which constitutes the main portion of the Hopkinton. It attains a thickness of from fifty to eighty feet and is used extensively in the manufacture of lime. The following sections are fairly representative. A quarry located near the northeast corner of the southwest quarter of section 20, Iowa township, shows the following succession of layers:

		FEET.
7.	Dolomite, decayed, earthy, yellow, containing much chert; the bedding planes destroyed by the breaking down of the rocks on weathering	10
6.	Dolomite, yellow, very cherty, weathering into layers about one inch in thickness	3
5.	Dolomite, very cherty	2½
4.	Dolomite, earthy, with chert	2
3.	Dolomite, yellow, bearing, near the center, a band of chert two inches in thickness. Weathering into thin layers one to two inches thick	2½
2.	Dolomite, yellow, free from chert	1½
1.	Dolomite, yellow colored, rather fine-grained, without chert, in a single layer	2

The above section illustrates the basal members of the Niagara as developed in the county. Numbers 1 to 3 represent the noncherty member, and numbers 4 to 7 represent the chert beds.

Hurst's lime quarry section east of the river at Hurstville, shows the upper member. The beds are as follows:

HURST'S LIME QUARRY SECTION.

		FEET.
3.	Dolomite, somewhat decayed, yellowish brown, weathered into layers from a few inches to three or four feet thick; containing Cerionites, crinoids and Pentamerus............	15
2.	Dolomite, massive, yellow, imperfectly separated into layers six to eight feet in thickness, which contain crinoids and Halysites and Favosites besides numerous individuals of Pentamerus..	30
1.	Dolomite, buff, crowded with rather small individuals of *Pentamerus oblongus*......................................	8

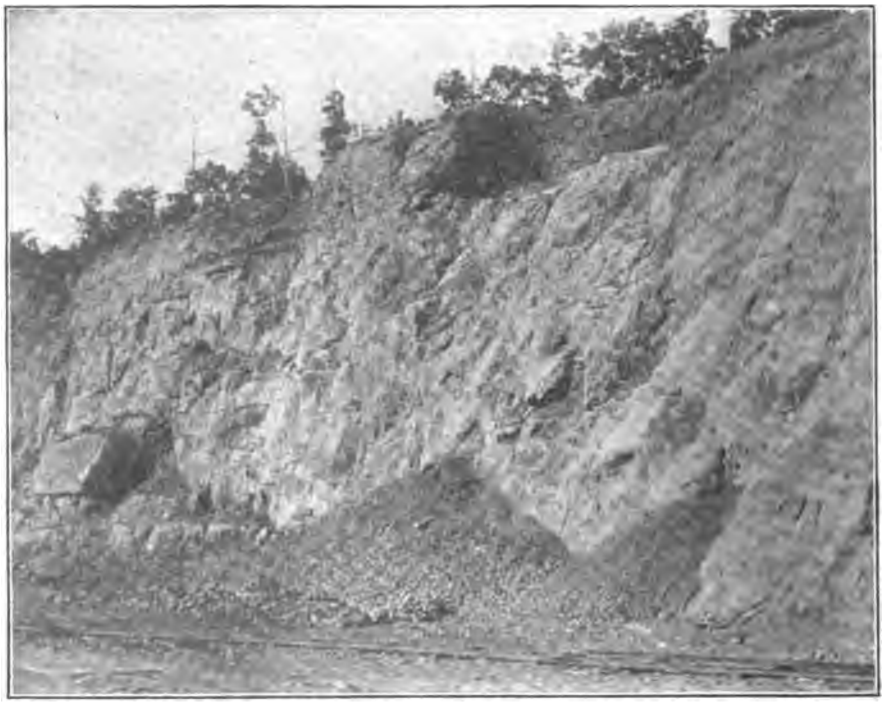

FIG. 20—Quarry furnishing stone for lime burning at Hurstville showing the massive character of this phase of the Hopkinton. Jackson county, Iowa.

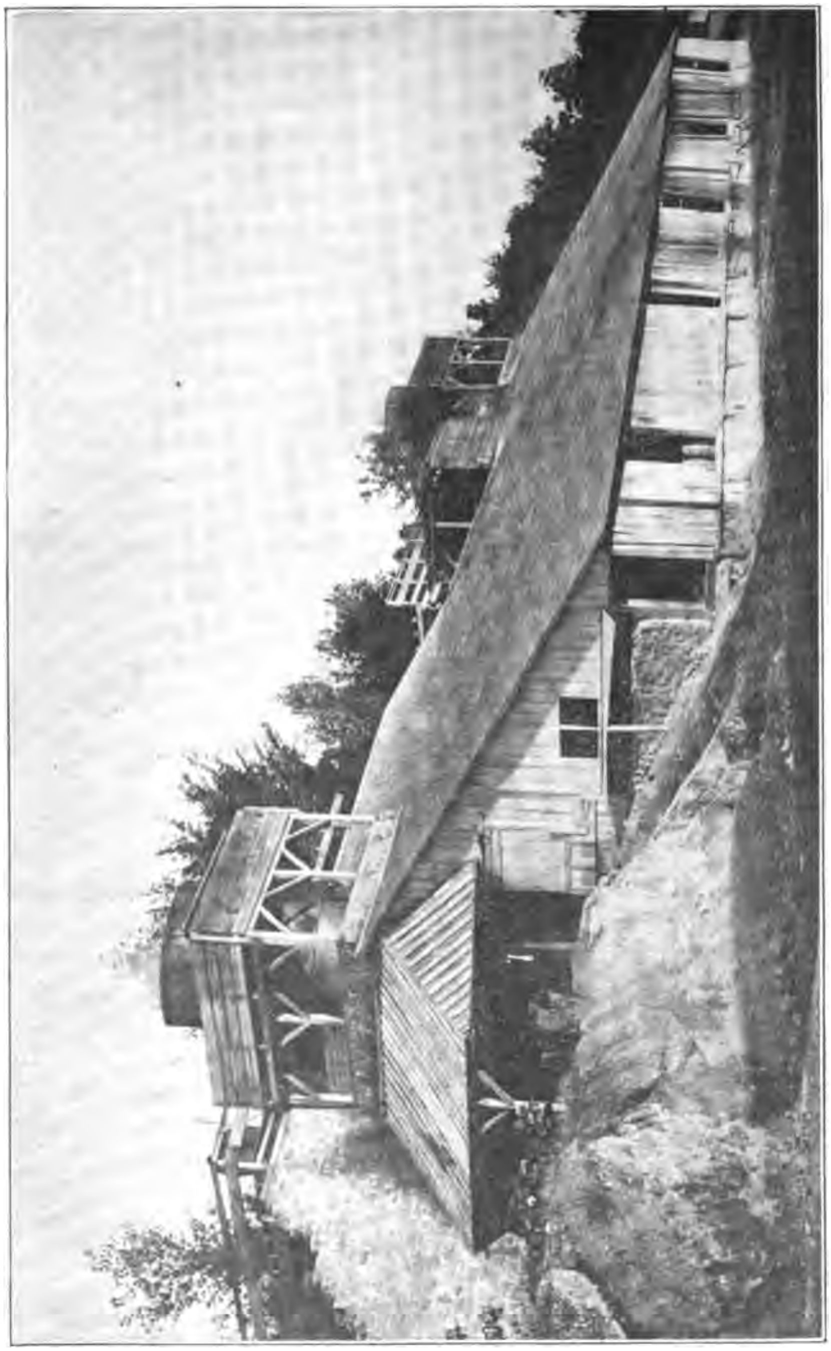

PLATE XL—A. Hurst Lime Company plant at Pinhook, showing elevated track, kilns and stock house. A fair representative of the lime manufacturing plants of the state. Jackson county, Iowa.

The entire assemblage of beds is used for lime burning. A heavy ledge ten to twelve feet in thickness occurs below number 1 of the section, but it contains chert in such quantities as to make it unsuitable for lime manufacture.

JOHNSON COUNTY.

The Niagara limestone occupies a small triangular area in the northeast corner of the county. The two phases of the Gower stage, well marked in other counties, are represented in section 2 along the Cedar river in Cedar township. The hard, fine-grained, sub-crystalline, light cream colored dolomite, aggregating twenty feet in thickness, represents the LeClaire beds, while the massive, vesicular, laminated dolomite, aggregating forty feet in thickness, is referred to the Anamosa stage.

A complete section of the bluff which faces the Cedar river in sections 2 and 3 in Cedar township is as follows:

		FEET.
5.	Loess, arenaceous, light colored	2-4
4.	Drift, pebbly, containing a large number of bowlders from one to three or four feet in diameter	4-6
3.	Limestone, laminated, without definite partings, cherty	30
2.	Limestone, yellow, non-laminated, in layers from four to eleven inches in thickness	10
1.	Dolomite, light colored, subcrystalline	20

Number 1 represents the LeClaire horizon and is essentially a pure dolomite admirably adapted for the manufacture of a high grade of lime. Numbers 2 and 3 belong to the Anamosa beds and have long found favor with the quarrymen, although the beds have never been developed extensively on account of lack of transportation facilities.

JONES COUNTY.

The Niagara limestone series comprises the country rock over the entire county and excellent exposures may be viewed along the principal streams. While each stage of the Niagara furnishes construction materials suitable for some economic use, the Anamosa stage and the evenly bedded horizon near the top of the Hopkinton, furnish the only building stones of commercial importance, while the hard, sub-crystalline, irregularly bedded LeClaire affords an inexhaustible supply of material suitable for high grade limes.

The building stone beds of the Hopkinton stage afford some excellent material, particularly in the neighborhood of Clay Mills, Canton and Temple Hill. Near Clay Mills the ledges vary from three to fourteen inches in thickness. The stone is generally of good color, it is firm, compact, without laminæ, and in the most trying situations, it resists admirably the action of the weather. All the exposures of the Hopkinton stage building stone are unfortunately located, so far as relates to facilities for transportation. Their only use for many years to come will be the furnishing of building material to supply local demands.

The commercial quarries are all dependent on the evenly bedded, finely laminated strata of the Anamosa phase of the Gower stage. The most important quarries of this phase are located near the western border of the county in Fairview and Cass townships.

The evenly bedded stone in the river bluffs west of Anamosa early attracted attention. The first extensive use of it was made by the United States army in constructing military roads while Iowa was yet a territory. Some of the old bridge piers built under the direction of the military engineers, are still standing and bear conclusive testimony to the durability of stone from this horizon. For some time the quarries were worked on a small scale and supplied only a local trade, but the market widened as the qualities of the stone became better known, and long wagon hauls were made in order to secure this material for use in structures of sufficient importance to justify such expensive methods of transportation. In 1852 stone was hauled from what is now Stone City to Mount Vernon for use in construction of one of the first buildings belonging to Cornell College.

Shipments by rail began from this locality in 1859, and after that time the stone industry of the region increased rapidly. From supplying a very restricted local trade, the business of quarrying and shipping stone has grown until it now reaches markets distributed throughout Iowa, Illinois, Wisconsin, Minnesota, South Dakota, Nebraska, Kansas and Missouri. Many of the most important structures in the several states named are built of Anamosa stone. It competes in Chicago and Minneapolis with the product of quarries more advantageously located, so far as distance is concerned. All the important railways of the northwest have used Anamosa stone in the construction of bridge piers. The stone has been used extensively in erecting the shops and other buildings at the Rock Island Arsenal. Iowa and Nebraska have both used it in building hospitals for the insane. It meets the requirements of all grades of architectural work from the humblest to the highest.

The Anamosa limestone varies locally, but in general it is composed of evenly bedded, perfectly laminated layers of impure dolomite that ranges in color through shades of buff to gray on the one hand, and almost white on the other. The beds are broadly undulating, but may be practically horizontal. The same beds thicken and thin gradually, but for limited distances are essentially parallel faced. The stone splits much more easily along bedding planes than in other directions, although clay partings are not common. Vertical joints are few and far between although more numerous in some quarries than in others. Texturally the stone varies considerably, from fine-grained, compact, non-laminated beds to somewhat vesicular, coarse-grained and evidently laminated beds. At Stone City the Anamosa beds have an aggregate thickness of sixty feet and are divided into two nearly equal parts by a porous, worthless ledge. The lower thirty feet is known as the "gray limestone" while the beds in the upper half constitute the "white limestone." The most valuable quarry stone comes from the lower or gray limestone. The upper beds are imperfectly cemented, and the cleavage along lamination planes is more perfect than in the beds below, for which reason the rock in this part of the quarry tends to split into thin slabs, and long exposure to the weather reduces it to chipstone. As a consequence its range of usefulness is somewhat limited, but it gives good service when used in ordinary masonry. The lower beds, on the other hand, lie below the level of the ground water, are more perfectly cemented, and furnish excellent material for almost all kinds of structural purposes. There are some planes in this division, however, along which the rock is vesicular, the cavities being of rather indefinite shape and ranging up to two or even three inches in diameter. Some of these are decorated with crystals of calcite or quartz or both. Cherty concretions are found in the upper limestone.

The most important quarries are located along the Wapsipinicon in Stone City and vicinity, and along Buffalo creek about three miles west of Anamosa, where the State quarries are located.

STONE CITY.

Four important companies are operating here at the present time, as follows:

J. A. Green & Son; H. Dearborn & Sons; J. A. Erickson; and John Ronen.

All of the quarries exhibit about the same sequence of beds, and all of the companies have about the same equipment. All have railway connections, own and use one or more channelers (single gang) and a number of steam drills, steam derricks, pumps for hydraulic stripping, and a crusher plant each to utilize the refuse. All of the quarries furnish crushed stone, riprap, rubble, bridge stone, flagging, and all grades of dimension stone. Professor Calvin has worked out a detailed section for Champion quarry No. 1, which fairly represents the district and also classifies the various ledges according to their uses. The section is given herewith. The quarry was opened by Mr. Green in 1867.

CHAMPION QUARRY No. 1. SECTION.

		FEET.	INCHES.
26.	Loess, varying in thickness, maximum	20	....
25.	Fine sand associated with loess, the sub-loessial sand of Norton	2–6	....
24.	Drift and residual clay	1	....
23.	"Shelly stone" the partially decomposed beds of the upper, or white limestone, broken into thin flakes or chips	2–10	....
22.	"White stone" splitting readily into smooth surfaced slabs, used chiefly for riprap	16	....
21.	"Rotten layer," a soft vesicular ledge of poor quality which separates the gray from the white limestone	2	4
20.	Compact fine-grained ledge, good building stone	1	5
19.	Same as 20	1	5
18.	Ledge of good building stone		11
17.	Same as 18		11
16.	Upper bridge stone, coarse	2	6

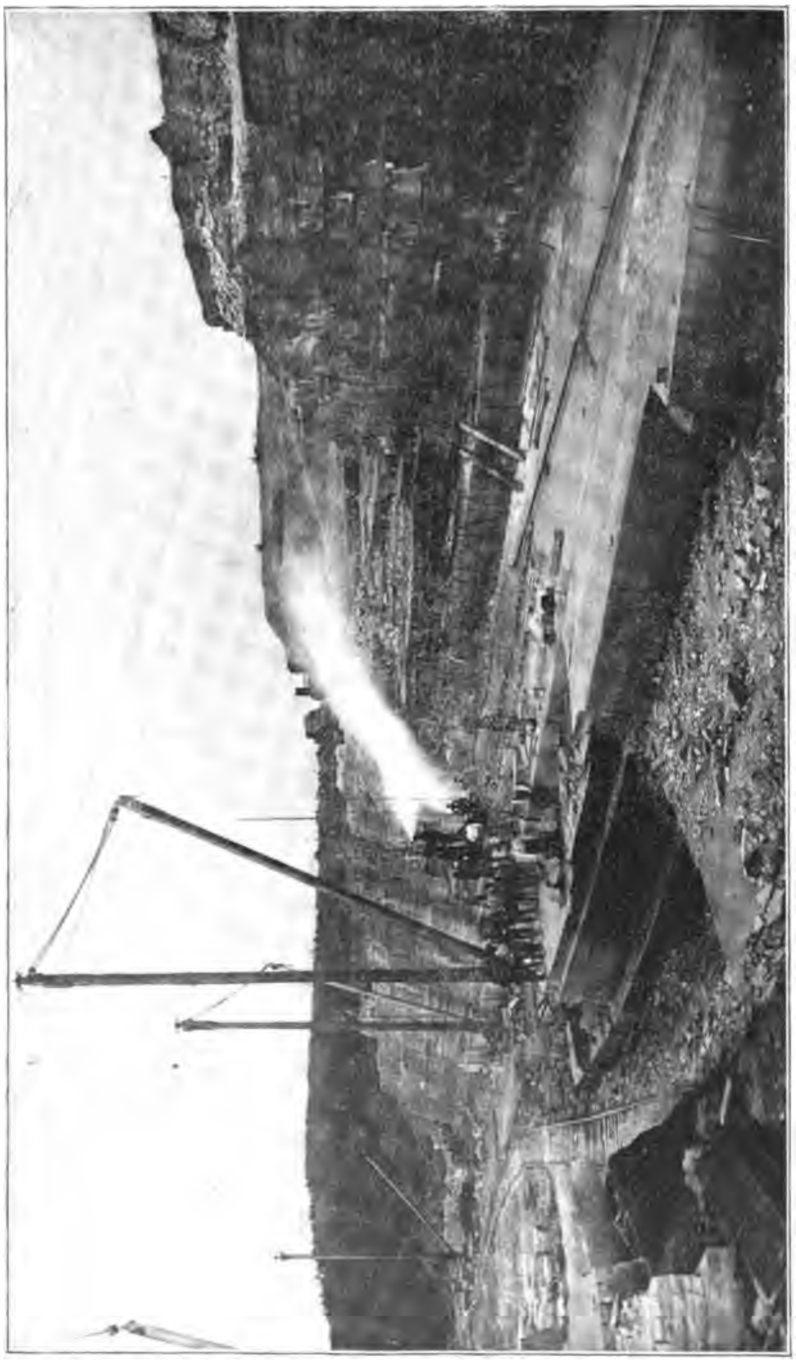

PLATE XLI—Champion quarry showing track and derrick arrangements and channeler. Stone City, Jones county, Iowa.

		FEET.	INCHES.
15.	Inferior layer containing many small cavities lined with calcite		10
14.	Fine-grained building stone	1	1
13.	Ledge containing at base a thin layer of very fine-grained, compact limestone, which cracks into angular fragments under the action of frost (the bands of very fine-grained limestone differing from the ordinary granular dolomite are called "flint" by the quarrymen)	1	3
12.	Ledge with bands of "flint"	1	11
11.	Solid ledge of good building stone	1	4
10.	Compact ledge, best quality afforded by the quarry	1	2
9.	"Wavy ledge" good for ordinary masonry; the laminæ are more or less undulated	2½-3	....
8.	Good building ledge		11
7.	"Flint ledge," compact limestone, breaking into angular fragments on exposure to weather	½-1	4
6.	Flagging ledge, easily split	1	4
5.	Ledge containing cavities lined with crystals	1	....
4.	Ledge of good building stone		11
3.	Lower flagging ledge	2	....
2.	Lower bridge stone ledge, very durable, though occasionally containing cavities lined with crystals	2	4
1.	Ledge that may again be split into blocks convenient for building purposes	3	....

Below the quarry stone there are here, as everywhere in this region, massive beds of the LeClaire limestone. The uppermost ledge of the LeClaire at the Champion quarry ranges from two and one-half to three feet in thickness and was formerly quarried to a limited extent for use in heavy bridge piers.

J. A. Green & Son also own and operate Champion quarry No. 2, which was opened in 1866, and they also own a quarry on Buffalo creek near the State Quarry.

STONE CITY QUARRIES.

The Stone City quarries were opened by Mr. H. Dearborn in 1869. They are now owned and operated by H. Dearborn & Sons. They are located near the middle of the south half of the northeast quarter of section 6, Fairview township. The quarry face forms a long sweeping curve about a quarter of a mile in length and nearly parallel with the sweep of the Wapsipinicon river that here flows close to the foot of the bluffs in which the quarries were opened. The quality of the stone and the succession of ledges are essentially the same as at the quarries already described. Overlying the stone is a bed of loess, sand and drift, with an average thickness of five feet and a maximum thickness of fifteen feet. Some six or eight feet of stone at the top of the quarry are to be counted with the refuse, the beds being broken into small angular pieces as a result of weathering prior to the deposition of the superficial drift and loess. These quarries expose the whole thickness of the "graystone" or lower half of the Anamosa beds, above which are serviceable beds of the "white stone," or upper half, having a thickness of ten or fifteen feet. The beds are worked out down to heavy ledges of non-laminated LeClaire. The quarries are capable of furnishing dimension stone from three to thirty-three inches in thickness, and of any desired length and width.

ANAMOSA QUARRY.

The Anamosa quarry was the first in this locality to ship stone abroad, the first shipments by rail being made in 1859. The quarry was opened by David Graham, but its present owner is Mr. J. Ronen, who has operated it since 1881. The Anamosa quarry is located near the northwest corner of the southwest quarter, section 5, Fairview township. Mr. Ronen's quarry is indeed double, for there are two openings a short distance apart. At the first opening the amount of clay stripping is very small. Beneath the clay there are a few feet of non-laminated worthless rock belonging to the Bertram stage. Then in descending order there follow fragmentary beds of the "white limestone," "shell rock," then the usual succession of ledges down to the lower bridge layer, or No. 2 of the Champion quarry section. Owing to the eastward dip of the beds at this locality, the lower bridge rock at the second Ronen quarry is too low to be worked, the lowest workable beds being about the level of the "flint ledge," or No. 7 of the section at the Champion.

STATE QUARRY.

In 1884, the present State quarry, or Penitentiary quarry, was opened. Formerly the stone for the penitentiary buildings at Anamosa was obtained from what is known as Champion quarry No. 2. In the year named the state bought property on Buffalo creek, in the southwest quarter of section 33, Cass township, and began operating the present quarry. The quarry is worked

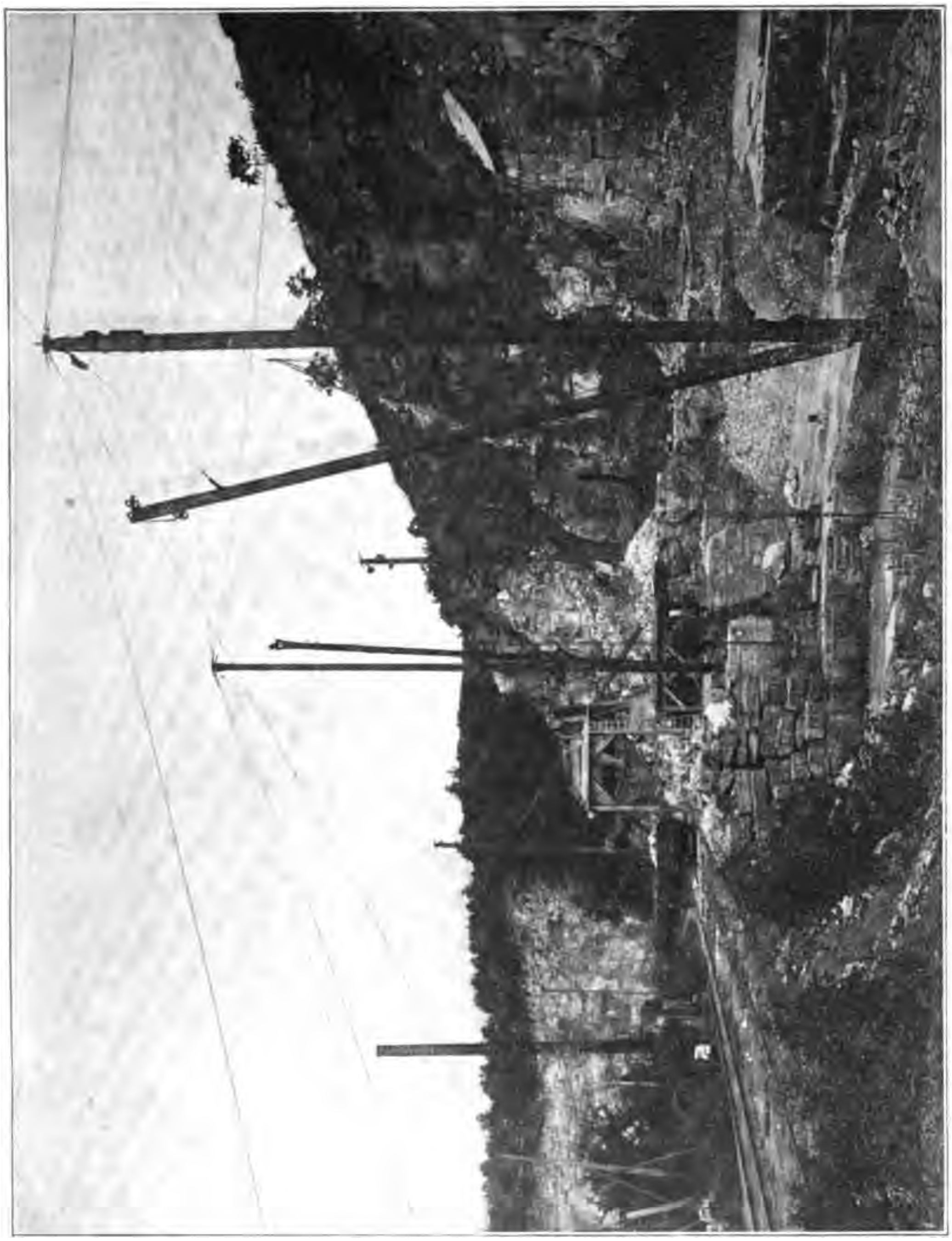

PLATE XLII—John Ronen quarry, showing arrangement of tracks, derricks and crusher plant. Stone City, Jones county, Iowa.

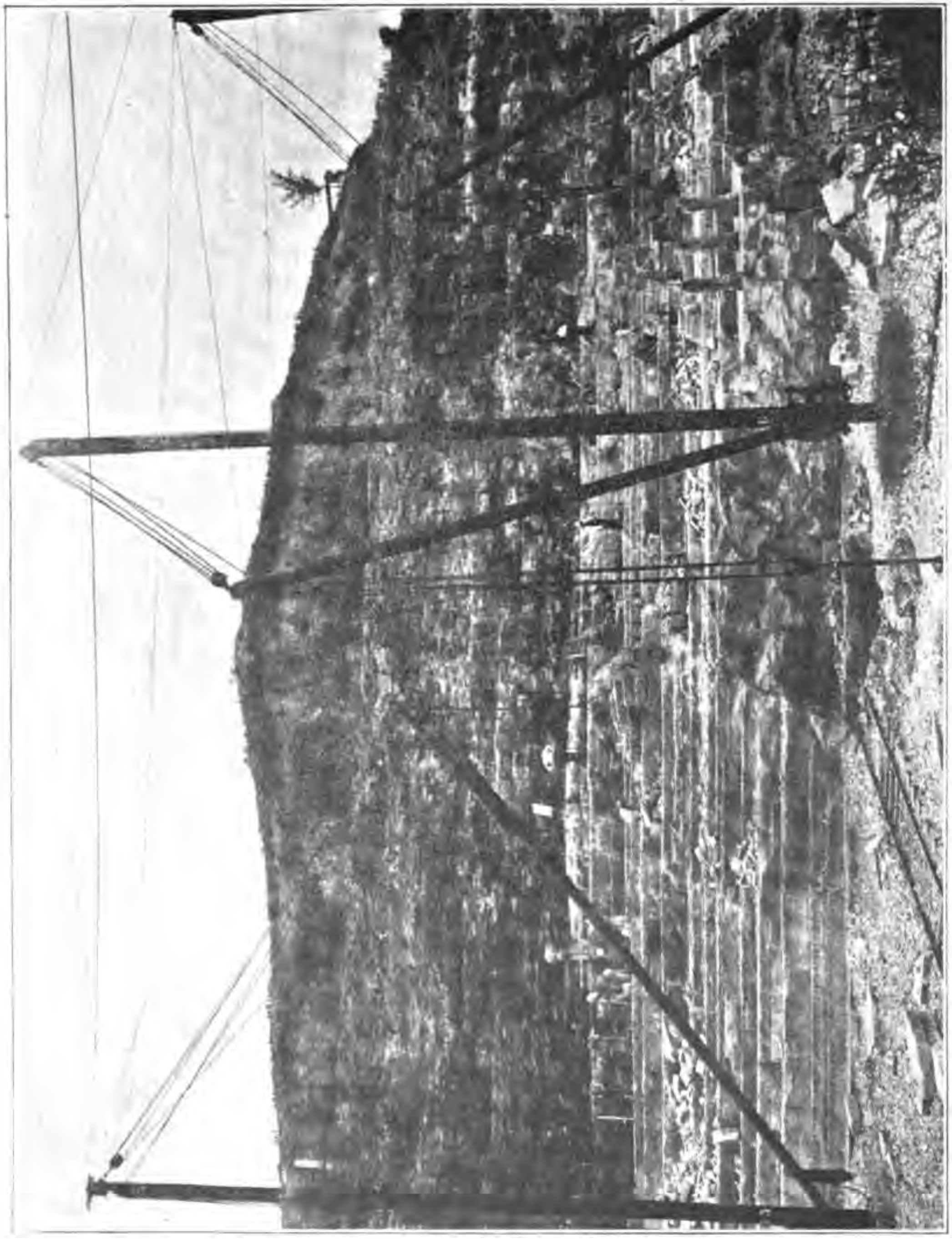

PLATE XLIII—State quarry, Anamosa, Jones county, Iowa. This quarry is unique amoung the larger quarries of the state in the absence of improved machinery. All power is hand power.

altogether by convict labor. Above the stone is a bed of loess and drift varying in thickness from a few inches to ten or twelve feet. Below the drift there are a few feet of decayed and broken "shell rock" belonging to the upper part of the "white stone" of the Anamosa phase. Lower in the quarry the ledges present the same features as in corresponding parts of other exposures. The Anamosa beds dip strongly to the north to accommodate themselves to the uneven upper surface of the LeClaire. Most of the work at this quarry is done by hand. There are several large derricks for handling the stone, but they are all operated by hand power. The stone is shipped over a spur of the Northwestern Railway, which runs up the valley of the Buffalo and accommodates all the quarries in this part of the Anamosa stone basin.

Other quarries have been opened in the vicinity, but show no new features worthy of mention.

In addition to the Anamosa and Stone City district, there are several small areas where the Anamosa beds are available and are being developed on a small scale. The two worthy of notice are near Olin and Hale. The Rummel quarry near Olin in Rome township may be taken as a type in the district. (Northeast quarter of the southeast quarter of section 24, township 83 north, range III west.) The quarry is opened in the low bluff on the west side of the valley of Sibyl creek. The stone belongs to the Anamosa phase of the Gower stage, and, except that it is buff in color, it corresponds well with the "gray stone," or lower portion of the formation as seen near Stone City. There are no definite bedding planes, but the rock cleaves readily along any of the planes of lamination. The surfaces of the laminæ are not so smooth and true as they are at the corresponding horizon near Stone City, but are irregularly undulated, apparently as a result of wave action at the time the beds were forming. The strata dip southeast at an angle of 5°.

In quarrying, only the simplest tools are used. Drills, crowbars, wedges, picks, shovels and wheel barrows make up the equipment. The soil or clay overlying the stone is only a few inches in thickness. For two or three feet below the soil the beds are broken into chips or spalls by weathering. With better means for quarrying, the greater part of the exposure would furnish marketable stone. The present method of quarrying, however, involves the use of large quantities of powder in a single blast. Drill holes are filled, or nearly filled, with powder, and the firing of such a blast loosens up great masses which are further separated and removed with pick, crowbar and sledges. The firing of these great blasts shatters the stone badly, rendering much of it worthless, and leaving even the best of it in condition suited for use in only the cheaper grades of masonry. Were the demand such as to justify the expense of putting in improved machinery, stone of high grade for many purposes might easily be obtained.

Several other quarries have been opened in the immediate vicinity but present no new features of importance.

The Hale quarry located near the center of section 11, Hale township, three-fourths of a mile east of the village of Hale, may be taken as a type of the district of the same name. The stone in the Hale quarry is finer than that in the quarries near Olin, but it resembles the Olin stone in the uneven, wave-marked surface of the several beds. The stone comes practically to the surface, there being only a few inches of soil overlying the upper beds. For about six feet at the top of the quarry the stone is much broken and disintegrated, as a result of weathering. Below the weathered portion the rock is solid and shows the characteristic lamination of this horizon. Partings between the beds are inconspicuous. The flexures of the beds and the dip in all directions (quaquaversal dip) forming a low dome near the north end of this quarry, are interesting features. The quarry supplies local trade only.

Quarries have also been opened south of the town and south of the river. An enormous amount of excellent material is available, but at the present time is not being utilized.

LIME.

Lime is not made on a commercial scale anywhere in Jones county, although beds suitable for its manufacture occur abundantly in the Hopkinton stage and the LeClaire phase of the Gower. Lime was formerly made at points near Anamosa, Stone City, Olin, Clay Mills, and Hale. There are LeClaire beds near the quarries on the Buffalo, and there are others near Anamosa and Stone City capable of furnishing material for manufacture into lime of the highest excellence. At the points named the facilities for shipping are good. There are many other equally good exposures of lime burning stone, but they are less favorably situated with reference to easy access to markets.

LINN COUNTY.

The Niagara limestone includes an irregular strip which crosses the east end of the county and comprises one-third of its superficial area. Tongue shaped projections extend up all of the more important streams, reaching Cedar Rapids along the Cedar. The Niagara presents its usual phases, including lower heavy bedded, coarse, cherty dolomite now referred to the Hopkinton, which is followed by the sub-crystalline, hard, brittle, often highly inclined beds of the LeClaire and these in turn, succeeded by the smooth, evenly bedded, gray to buff, dolomitic layers of the Anamosa phase of the Gower, which are followed in turn by hard, compact, brittle, magnesian limestones, which Norton has designated the Bertram, and which complete the series.

Practically all of the important quarries in the county are operating in the Anamosa beds which are typically developed at Stone City, while the lime producers are developing the LeClaire beds. A wealth of exposures occurs along nearly all of the principal streams. A few only, are given by way of illustration. The sections already given for Stone City and vicinity, may be taken as a standard, as the beds are more extensively exposed and developed at that point than at any point in Linn county. At Mount Vernon practically the same beds appear and differ only in being of slightly coarser grain. The quarries are connected by a switch with the main line of the Chicago and Northwestern railway and are equipped with a steel derrick, cars, trackage, an inclined plane to a No. 3 Gates crusher and the usual number of elevators, screens and bins. The quarry section shows the following sequence of layers:

MOUNT VERNON SECTION.

		FEET.
4.	Soil, loess and drift	0–10
3.	Limestone, dolomitic, weathered to spalls and chip-stone	6–8
2.	Limestone, dolomitic, in layers up to eight inches in thickness	3–5
1.	Dolomite, in layers ranging from six to thirty-six inches in thickness, aggregating, exposed	12

The pit is filled with water at the present time so that number 1 is obscured very largely. The property is in litigation and the quarry has not been operated save in a very small way during the past few years. Stone suitable for bridge work, caps and sills, dimension and cut stone purposes is available and equal in quality to any produced from the Niagara in Iowa. Other quarries have been opened in the district, some of which are still operated intermittently.

Splendid sections of the Anamosa stone may be viewed along the Wapsipinicon northwest of Stone City. Several quarries have been opened at Waubeek and vicinity, but owing to the lack of proper transportation facilities, stone is produced to supply the local demand only. The beds available are essentially the same as those exploited at Stone City and are as easily accessible.

LIME.

The LeClaire limestone supplies all of the lime burned in the county. Kilns have been built and operated at Viola and Mount Vernon, but recently only the plant at Viola has been in operation and even that only intermittently. The Viola Lime Company is developing the highly inclined beds of the LeClaire, which attain a thickness of about twenty feet and rest on heavy beds of dolomite which are practically horizontal. The upper beds only are used for lime and consist of a hard, brittle, subcrystalline dolomite which is only slightly vesicular. The company is using the Eldred process of manufacture and uses Hocking Valley coal for fuel. The lime produced is one of the best in the state.

SCOTT COUNTY.

The Silurian rocks in Scott county belong to the Niagara series and form the country rock over the northern two-thirds of the county. The lowest stage of the Niagara, the Hopkinton, has not been recognized in the county and all of the Silurian limestones are referred to the upper stage, the Gower of Norton. Exposures of the Gower occur in all the townships north of a line extending from Valley City slightly northwest to about five miles north of Durant, save in Sheridan and Lincoln townships where the drift completely conceals the country rocks.

The two distinct lithological phases of the Gower are well shown in the county. The pure, hard, sub-crystalline dolomite, free from chert and especially adapted to the manufacture of lime, is known as the LeClaire from its occurrence at the village of that name. The upper beds, comprising light buff, vesicular, evenly bedded dolomite, are generally known as the Anamosa stone.

A distinguishing characteristic of the LeClaire rocks is the absence or abnormal disposition of its bedding planes. It often apparently occurs in large mounds in which scarcely a trace of stratification is visible. Such an example may be seen at Schmidt's lime quarry south of Dixon. The LeClaire often exhibits false bedding on gigantic scale; the beds being inclined from zero to 40 degrees. The dip is exceedingly inconstant, varying both in inclination and direction in short distances.

The Anamosa beds are intimately associated with the LeClaire, and usually lie in even and horizontal or slightly undulating layers. Chemically the Anamosa stone is a dolomite, differing in its constituents from the LeClaire in the larger per cent of the impurities present. In Scott county the stone runs in even parallel courses, whose thickness depends largely upon weathering. Layers from eight to twelve inches are the most common and blocks can be taken out of almost any dimensions. The Anamosa beds are generally laminated, but grade downward insensibly into the LeClaire by the lamination planes becoming obscure, and the stone becoming sub-crystalline. By another type of lithological variation the rock becomes hard and compact with a sub-conchoidal fracture, resembling the lithographic phase of the Devonian. These layers are often termed "flint" by the quarrymen, although destitute of silica.

Outcrops of both the LeClaire and Anamosa are generally distributed along all of the principal waterways. Numerous quarries have been opened, but with a few exceptions they are of local importance only. A few typical exposures are given below. The LeClaire beds are exposed and have been quarried on sections 13, 14, 15, 18 and 22, Liberty township, and section 5 in Cleona township, in the west end of the county. The beds range from twelve to thirty feet in thickness and show the usual LeClaire characteristics. The LeClaire also occurs in section 7, Allen Grove township, where it has been burned for lime for more than a half century, and at a number of points near Big Rock. It occurs and has been quarried near Princeton and LeClaire.

The Anamosa beds have been developed extensively in the vicinity of Princeton and LeClaire. North of the latter place the LaClaire Stone Company has opened and is operating the largest quarry in the county. The quarry is connected with the Iowa and Illinois railway.

The beds exposed are as follows:

LECLAIRE SECTION.

		FEET.
8.	Loess and drift, thickness variable..........	0–10
7.	Limestone, buff, dolomitic, much weathered, thinly bedded and often almost clayey in appearance...	10–30
6.	Dolomite, cavernous, most vesicular layer in the quarry, hard and brittle, sub-crystalline; some of the cavities contain crystals....................................	5–6
5.	Dolomite, thinly bedded and much weathered in places; often hard and brittle and bluish when fresh...	4
4.	Dolomite, heavy bedded, somewhat vesicular and irregularly indurated.................................	2
	Spring line here.	
3.	Dolomite in remarkably even beds and very soft when first quarried. The best dimension stone in the quarry; in six layers......................................	6
2.	Dolomite, in heavy beds, upper portion shows a tendency to split irregularly; brittle..........................	6
1.	Dolomite, thinly-bedded, cavernous in places, exposed	4

The quarry is equipped with steam drills and derricks and an Austin crusher plant. The stone is carried from quarry to cars and crusher by means of derricks and very little trackage is required. Three sizes of crushed stone, in addition to the dust, are put upon the market. The quarry also supplies rubble and riprap and all sorts of dimension stone.

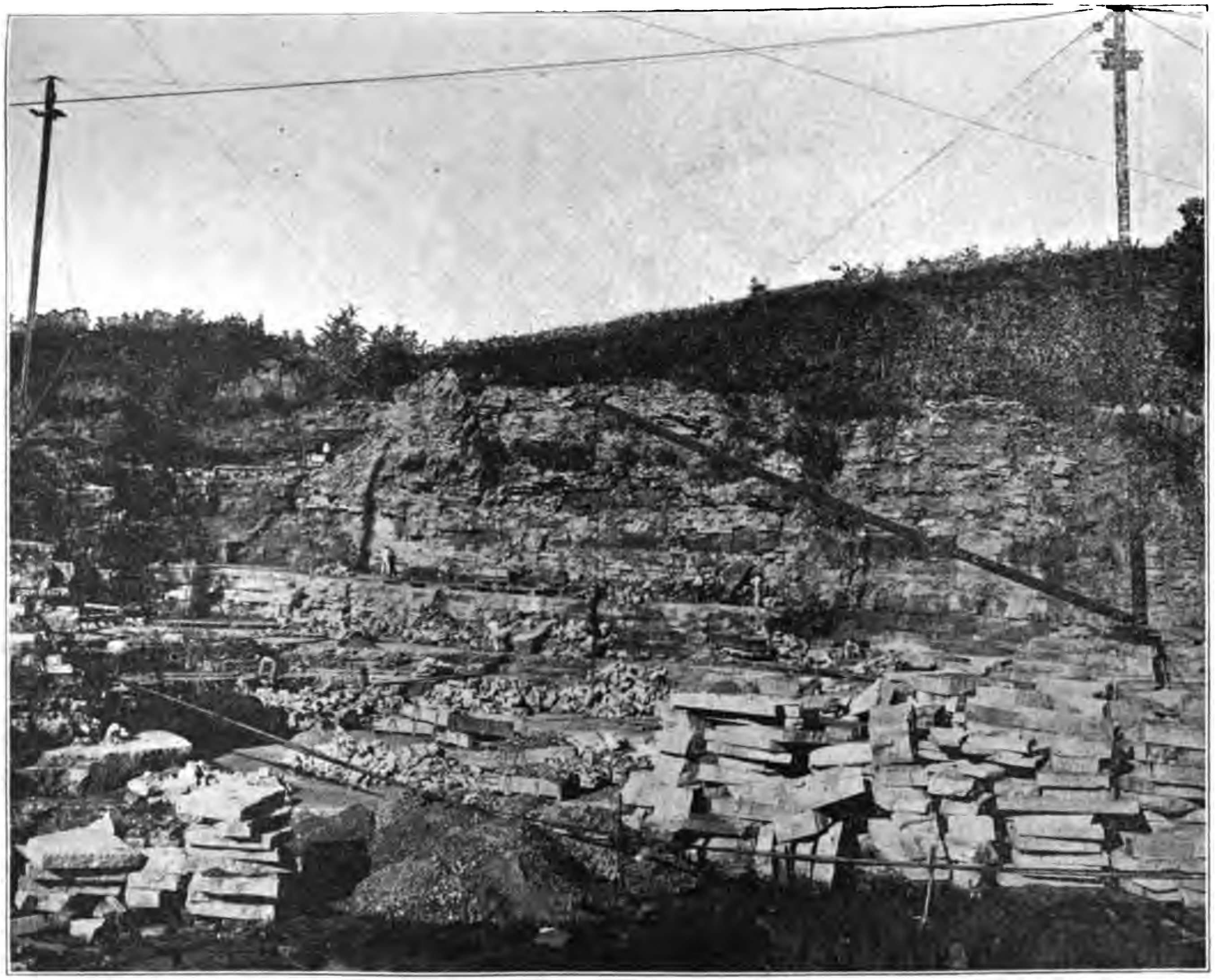

PLATE XLIV—General view of LeClaire Stone Company quarry, near LeClaire, Scott county, Iowa. The handling of material is done by derricks alone.

The Anamosa beds here dip toward the northwest at a low angle.

Other quarries have been opened near LeClaire but show no new features. The beds developed are usually less regular than those just described. Of the large number of quarries which have been worked from time to time in the vicinity of Princeton, only one is given here. Several quarries have been opened at the base of the high bluffs which skirt the valley of the Wapsipinicon, northwest of the town of Princeton; one of the most extensive is located on the northwest quarter of section 34, Princeton township. The succession of beds is as follows:

		FEET.
5.	Superficial deposits resting on unpitted rock surface	2
4.	Limestone in thin layers, mostly from 2 to 4 inches thick, a few reaching 8 inches, and some consisting of thin calcareous plates	12
3.	Limestone, close, granular, slightly harder and more brittle than typical Anamosa stone, in even, horizontal courses from 6 to 20 and 24 inches in thickness, buff in color, with few cavities and smooth surfaced, including a foot or so of thinly laminated "flinty" limestone	14
2.	Limestone in layers from 2 inches to 18 inches, semi-crystalline	7
1.	Limestone in thin, gray, crystalline, calcareous plates	5

Beds intermediate in character between the Anamosa and LeClaire beds, supply an abundance of quarry stone. Small quarries have been opened in Liberty, Cleona, Butler, LeClaire and Pleasant Valley townships.

These intermediate beds are buff, non-laminated, regular and heavy. They are generally highly vesicular, and often subcrystalline. A representative section may be seen in a small quarry on the northeast quarter of section 1, in Liberty township. Natural ledges, aggregating twenty or thirty feet, appear along the gorge of the Wapsipinicon and show an earthy dolomite in massive beds up to three feet or more in thickness. The stone is non-laminated and is sub-crystalline in places. The bedding planes are rough and cavities of considerable size are present. In Cleona township a quarry located on the northwest quarter of section 7 shows the following succession:

		FEET.
4.	Limestone, magnesian, horizontally bedded, brown, semi-crystalline, weathering into small chipstone, with one or two 6-inch layers more resistant	9
3.	Limestone, magnesian, light gray, laminated, earthy, in places vesicular, more thinly bedded than above, passing in places into thin beds. This includes a distinct layer of buff magnesian limestone 1 foot thick	6
2.	Limestone, magnesian, gray, irregularly bedded, thin layered, weathering to small, sharp angled chipstones	6
1.	Limestone, magnesian, brown, earthy, ocherous, in thicker beds than above, partly cemented	3

Similar but less extensive sections may be viewed at numerous points in the northeastern townships.

WINNESHIEK COUNTY.

Several small outliers of the Niagara limestone appear in Washington township and are believed to be the northernmost outcrops of that formation in the state. The stone commonly representing the Niagara here is a yellow-buff, dolomitic limestone. Some of the layers exposed in an old quarry west of Festina comprise a hard, buff, sub-crystalline dolomite comparable with typical Niagara dolomites exposed farther south. The beds are of small importance and have been but little developed in Winneshiek county.

The Devonian.

The Devonian as developed in Iowa comprises a rather diversified assemblage of limestones and shales. The latter are of interest as a quarry product only so far as they are suitable for the manufacture of Portland cement. The limestones vary greatly in composition, texture, state of induration, thickness of beds and weathering qualities. They range in composition from a pure calcium carbonate as in the white, compact, brittle limestones, developed in Cerro Gordo and Mitchell counties, to typical granular dolomites, and argillaceous limestones. They range texturally from rather coarse sub-crystalline limestones and dolomites to compact lithographic stone. The range in state of induration is equally pronounced, from hard limestone which gives a metallic sound when struck with the hammer to soft, earthy limestone. In certain horizons the beds are thin and flaggy while in the "State Quarry" type, the beds attain thicknesses of five or six feet. The beds in the so-called Fayette sub-stage are much broken or crushed and are practically worthless for coursing stone. All of the divisions of the Devonian furnish some quarry stone, though the most important horizons are found in the Wapsipinicon, Cedar Valley and State Quarry stages. In all three of these stages, deposits ranging from hard, brittle limestones to dolomites prevail and afford excellent material for crushed stone purposes.

The Devonian beds occupy a belt varying from twenty-five to seventy-five miles in width and extending across the state in a northwest-southeast direction. The belt is included between Worth to Howard counties on the north and Muscatine and Scott on the south. The most important quarries belonging to the Wapsipinicon stage occur in the southern portion of the area; the Cedar Valley stage is quarried throughout, but perhaps most extensively in the northern portion while the State Quarry stage is limited to Johnson county. Detailed descriptions follow by counties.

BENTON COUNTY.

All of the outcrops of indurated rocks in the county belong to the Devonian. All of the important sections are found in the northeast third of the county, along the Cedar river and its immediate tributaries. The best quarry rock belongs to the Coggan beds which are at the base of the Devonian series as exposed in Benton county. Good exposures of these beds are practically limited to Cedar, Harrison and Taylor townships where they have been exploited at a number of points. The rock is essentially a highly magnesian limestone, very hard and fine-grained and yellowish in color, imperfectly bedded and non-fossiliferous. These dolomitic beds outcrop low in the bluffs and are overlain by brecciated limestone belonging to the Fayette sub-stage. Near the southwest corner of section 31, Harrison township, a representative exposure may be seen. The quarry operated by Aungst Brothers is in the west bluff of the Cedar river and shows the following beds below the drift:

		FEET.
2.	Limestone, brecciated, gray; the angular fragments usually small and very fine-grained in texture, non-fossiliferous	20
1.	Limestone, buff, magnesian, massive ledge which is fine-grained, imperfectly separated into layers one to two feet in thickness, non-fossiliferous	12

Similar exposures are to be found in section 36, Cedar township, and section 6, Taylor township. The beds have been quarried at both places. The brecciated beds have been developed at several points in addition to those just mentioned, notably on the south bank of Prairie creek, near the northeast corner of section 10, Taylor township, where the following succession of beds may be studied:

		FEET.
6.	Soil and drift of variable thickness	
5.	Limestone, shattered, light gray, fragments irregular in size and shape	8
4.	Talus slope	12
3.	Limestone, light gray, in broken layers from three to six or seven inches in thickness	1½
2.	Limestone, gray, made up of imperfect layers two to eight inches in thickness	4
1.	Limestone, light gray, a rather massive bed which is cut by numerous oblique joints into rhomboidal blocks, some of which are slickensided; material weathers readily into small, irregular fragments	8

Some years ago the above quarry was operated by the Iowa Paint Company of Vinton. Number 1 was pulverized and used as a basis in the manufacture of paint. The company has since moved its plant to Fort Dodge, Iowa. In Benton county, as elsewhere, the brecciated stone is imperfectly bedded and only rough, irregular blocks can be obtained. It is suitable only for rough masonry and crushed stone purposes. At the present time there is not a single crusher in the county and as a consequence, the brecciated beds are not in demand.

A large percentage of the stone produced in the county comes from the beds of the Cedar Valley stage. While the grade of stone furnished by these beds is not equal to the stone lower in the series it is suitable for foundations for ordinary buildings, for walling up dug wells and for retaining walls. The stone has been used to some extent for bridge work with fair results.

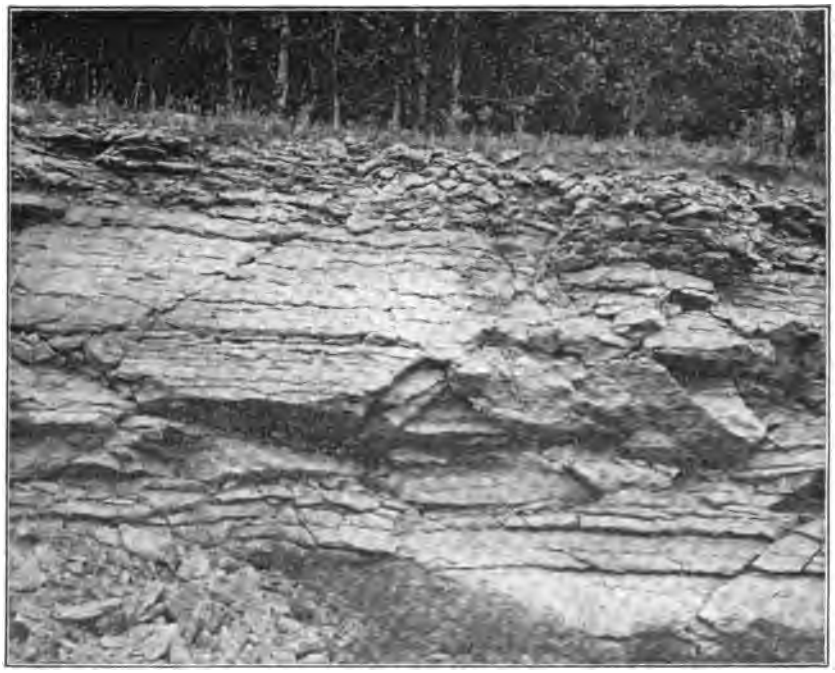

FIG. 21—Exposure in an abandoned quarry, section 15, Taylor township. The *Acervularia davidsoni* coral reef appears at the top. The view shows the character of the layers between this coral reef and the zone of *Acervularia profunda*.

Near the county line a quarry has been opened a short distance below the bridge and near the northwest corner of section 6, Harrison township. The layers exposed are as follows:

		FEET.
12.	Dark colored, fine-grained, pebbleless soil	1
11.	Bed of reddish brown clay, containing numerous pebbles of quartz and greenstone with occasional granite bowlders of larger size	2
10.	Layer of much decayed fragments of brown limestone; without fossils	3
9.	Bed composed of two layers of yellow, earthy limestone, each about eight inches in thickness, fine-grained and without fossils	1⅓
8.	Bed of gray limestone which weathers into thin layers about one inch in thickness; without fossils	3
7.	Layer of very hard, earthy limestone, yellow in color and fine-grained in texture; fossils wanting	⅚
6.	Bed made up of layers of buff, earthy limestone two to six inches in thickness, which are fine-grained in texture and non-fossiliferous	3½

		FEET.
5.	Layer of yellow, impure limestone which weathers into indistinct layers three to six inches in thickness; without fossils	1½
4.	Layer similar to number 5 above	2
3.	Yellowish brown layer of fine-grained, impure limestone; carrying occasional concretions of chert which are most numerous adjacent to the division planes	2½
2.	Layer of variable, impure limestone, fine-grained and very hard. Near the base of this layer chert nodules are abundant	2
1.	Bed made up of two layers of buff, earthy limestone in which, at irregular intervals, occur bands and numerous masses of chert; without fossils; to base of the exposure which is about four feet above the level of the water	4

The layers in this quarry are cut by numerous, oblique joints which divide the ledge into large rhombic masses. The material of which the beds are composed is mostly a fine-grained, earthy limestone. Many of the layers are strongly magnesian, and some of them are so thoroughly dolomitic that they respond but slightly to the application of cold hydrochloric acid. The entire ledge is regularly bedded, and furnishes quarry stone of convenient dimensions and durable quality.

Similar sections may be seen down the river, and quarries have been opened at several points on both sides of the stream. Near the northwest corner of section 27, Taylor township, a quarry has been opened in the east bank of Mud creek. The beds exposed are as follows:

VINTON SECTION.

		FEET.
10.	Soil, dark colored, fine-grained and without pebbles	½
9.	Gravel and sand stained a reddish brown color	2
8.	Limestone, composed almost wholly of coral fragments	5
7.	Limestone, hard, gray, weathers into thin pieces, crinoidal	3
6.	Limestone, light gray, very hard, which weathers into layers ranging from four inches to a foot in thickness	6
5.	Limestone, gray, very hard, composed largely of brachiopod fragments	1½
4.	Limestone, similar to 5, but finer textured	1¼
3.	Limestone, drab, similar to number 8, but less compact	1
2.	Limestone, white, fine-grained; shows a bluish tinge in a fresh ledge, cherty, much shattered and weathering into thin layers	2
1.	Limestone, very hard, cherty and crinoidal	1½

The lower two numbers are supposed to belong to the brecciated stage and are equivalent to number 1 in the old quarry of the Iowa Paint Company. In the above section they are hard and the most durable stone that the quarry produces. It is used extensively in Vinton. In addition to the lower beds, numbers 4 to 7 furnish an acceptable material for foundations and the rougher grades of masonry.

On the south bank of Bear creek near the middle line of section 14, Canton township, a quarry shows the following beds which may be considered representative for this part of the county.

SHELLSBURG SECTION.

		FEET.
9.	Soil, dark gray, without pebbles or bowlders	1½
8.	Drift	2
7.	Limestone, much decayed	3
6.	Limestone, coralline	2½
5.	Limestone, light gray, weathers into chipstone	1½
4.	Limestone, gray, hard, in places forms a single ledge, fossiliferous	4
3.	Limestone, dark gray, two ledges of about equal thickness	3½
2.	Limestone, similar to 3, but shelly	1
1.	Limestone, in three layers	4½

East of north of the Shellsburg quarry on the Cedar river, Wild Cat bluff presents an escarpment of more than forty feet of limestone. Nothing especially new is developed however.

Away from the river, westward, quarries have been opened on section 8 in Cedar township, and section 28 in Jackson township, near Garrison. The latter is the more representative and is given below.

GARRISON SECTION.

		FEET.
9.	Soil and drift	5
8.	Limestone, light gray, sub-crystalline, very hard, and somewhat brecciated, containing numerous spherical stromatoporoids	3
7.	Limestone, gray, massive, dense, composed largely of various species of stromatoporoids and masses of Idiostroma-like stems, few of which can be recognized. This bed is also somewhat brecciated in places	6
6.	Limestone, hard, gray, weathers into two indistinct layers, and contains masses of spherical stromatoporoids	3½
5.	Limestone, very hard, white, sub-crystalline; without fossils	1½

	FEET
4. Limestone, yellowish gray, non-fossiliferous, fine-grained and very hard. The upper portion bears numerous small cavities, the largest of which are nearly one inch in diameter..	4
3. Limestone, dense, gray, fine-grained and very resistant to weathering; without fossils................................	3½
2. Limestone, composed of several layers, very hard, fine-grained, white in color and without fossils. The layers are six to fifteen inches in thickness...........................	5½
1. Limestone, bed made up of two layers, yellowish brown. The material is fine-grained, and contains no fossils............	3½

The upper and middle beds in the above section more closely resemble the beds of the Cedar Valley stage as developed in other counties, notably, Johnson county to the south, and Mitchell, Floyd, and Cerro Gordo, to the north. While an abundance of stone crops are available, and numerous quarries have been opened in times gone by, none of the quarries now in operation are of more than local importance as no stone is exported.

LIME.

Lime has been manufactured at several points in the county but at the present time only one kiln is operated and that intermittently. The magnesian beds of the Coggan are used and a good grade of lime is produced. The entire output is consumed at home.

BLACK HAWK COUNTY.

With a single exception all of the indurated rocks which appear at the surface in the county may be referred to the Cedar Valley stage of the Devonian. A very insignificant natural exposure of Wapsipinicon beds, according to Arey, appears along Spring creek, on the northwest quarter of section 13 in Fox township. It is of no importance from an economic view point. The Cedar Valley limestone presents numerous outcrops along the principal drainage lines, and quarries have been opened at many points. None are of large capacity and but few are ambitious to supply more than their own immediate localities. The principal quarry districts are in the vicinity of Cedar Falls, Waterloo and Laporte, while some quarries of secondary importance near Raymond, and two quarries about three miles east of Eagle post office supply the country trade.

For the Cedar Falls district the Nielson quarry may be taken as a type. It is located west of Main street about one-eighth mile west of the old Carpenter quarry. The principal beds exposed are as follows:

		FEET.
15.	Limestone, firm, yellowish, with intermingled "geest".....	3
14.	Limestone, lithographic, somewhat nodular, more or less weathered and inconstant..............................	2
13.	Shale, yellowish clay, with interbedded hard ledges in places, very variable in thickness, averaging.....................	1½
12.	Limestone in three layers, finely laminated, fine-grained and smooth, slightly iron-stained, 6, 2 and 10 inches respectively from top down..	1½
11.	Limestone, variable, sometimes splitting easily into layers, sometimes firm and even textured, finely sub-crystalline, with earthy streaks, rusty in patches, crystals in pockets and calcitic sheets intersecting one another, making pitlike areas along the joint planes, averaging..................	1
10.	Limestone, fine-grained, bluish gray, with occasional patches of crystals, quarried in sheets, and used for window and door sills and caps, and ashlar..........................	⅚
9.	Bluish gray stone of good quality, grading into a shaly parting below...	½
8.	Limestone, gray, finely brecciated, with seams of crystals below, upper part yellowish, earthy. If quarried in cold weather, it is reduced to fragments readily, but, if dried out before freezing, it makes a durable stone............	⅔
7.	Limestone, firm, fine-grained, bluish gray, with occasional pockets of crystals, in two layers. Makes an excellent range stone. The lower layers yield fine large flags.......	1
6.	Limestone, uniformly fine-grained, yielding flags...........	7/12
5.	Limestone, heavy-bedded, shelly on the under side, abounding in crystals, bluish gray..............................	1½
4.	Limestone, fine-grained, more or less streaked or banded...	1⅔
3.	Limestone, light colored, becoming still lighter in color below, often weathers in a remarkable way, yet makes a durable stone, when it has been dried out................	1½
2.	Limestone, yellowish, full of pockets.......................	1
1.	Soft, chalky stone, exposed.	

Numbers 1 and 2 are no longer worked.

North and northwest of Cedar Falls, there are no important rock exposures. Limestone outcrops at numerous points on both sides of the Cedar river and doubtless good structural materials might be developed at small expense should the demand warrant it.

North and northwest of Waterloo, quarries have been opened in the well marked stone-supported terrace which faces the Cedar river. The most important section may be seen in the quarry of the Waterloo Stone Company, which is located on the northwest quarter of section 14, township 89 north, range XIII west. The beds worked at this point are as follows:

WATERLOO STONE COMPANY'S QUARRY.

		FEET.
8.	Detritus and wash	6
7.	Limestone, hard, dolomitic, sub-crystalline	1
6.	Limestone, weathered, yellow	1
5.	Limestone, heavy bedded, gray-blue, cherty toward the top	12
4.	Limestone, blue, thinly bedded, slightly argillaceous	3
3.	Limestone, buff, concretionary, with numerous cherts	3
2.	Limestone, gray-blue, sub-crystalline, cherty, weathers buff	3
	Shale parting	⅓
1.	Limestone, buff to yellow, exposed	2

All of the beds tend to weather into thin layers and weathered surfaces present a decidedly shattered appearance. Number 3 appears to break down especially easily when subjected to repeated freezings and thawings. The cherts are small and more or less irregularly distributed throughout the entire mass. The joints are stained a brownish yellow and all of the quarry rock tends to weather the same color on long exposure.

Two samples of the rock from the McWilliams-Mowry quarry were analyzed and found to be strongly magnesian. The analyses were as follows:

	1	2
Insoluble	1.92	.....
Iron and alumina	4.20	.....
Calcium carbonate	63.59	.....
Magnesium carbonate	30.92	12.18
Sulphur	Trace	.....

Number 1. Blue unweathered limestone.
Number 2. Yellow limestone.

In Laporte and vicinity a large number of quarries have been opened and operated intermittently for many years. The product is sold and was formerly reported in the mineral statistics as "La Porte Sandstone" on account of its sugary or subcrystalline character.

A quarry located along the wagon road about one-half mile northwest of town will serve as a type for the district. The beds exposed are given herewith:

		FEET.
4.	Drift and soil; some of the quarries in the near vicinity show a much thicker overburden	2+
3.	Limestone, considerably shattered; stained yellow to brownish yellow; bedding planes disappear upward	10
2.	Limestone, brownish yellow to buff, irregularly bedded, quartz geodes and chert nodules present	2
1.	Limestone, gray-blue, presents a granular appearance; in medium heavy beds ranging from 15 to 24 inches; joints weathered a yellowish brown, fossiliferous; calcite balls and geodes common	10

The beds dip to the southwest at an angle of about five degrees and appear to thicken down the dip. They appear to be strongly magnesian, especially the lower beds, which are subcrystalline.

Quarries have been opened on either side of the Eagle-Big Creek township line near the middle. The quarry west of the line is the more extensive and is as follows according to Arey:

EAGLE TOWNSHIP QUARRY.

		FEET.
13.	Limestone, thin-bedded, broken stone	7
12.	Limestone, in two layers, blue where unweathered	4½
11.	Limestone, in three layers, hard, compact, good quality, durable, brittle, having conchoidal fracture, with drab nodules of varying sizes, and in the upper part with stromatoporoid masses thoroughly coalescent with the rest of the rock	5
10.	Limestone, bluish, earthy, much jointed and irregularly bedded	3
9.	Limestone, dark, drab, calcitic at top	1½
8.	Limestone, blue, buff where exposed, calcite plentiful, in seven or eight layers	1⅚
7.	Limestone, drab	⅚
6.	Limestone, buff, earthy, finely streaked with yellow lines	2⅙
5.	Shaly partings with very wavy lines of contact above and below	½
4.	Limestone, hard, brittle, drab, middle portion developing layers	3⅙
3.	Limestone, blue, of good quality, firm, finely crystalline, with pockets of crystals, thickness not taken	
2.	Limestone, gray, finely sub-crystalline, yielding good flags	½
1.	Limestone, gray, somewhat crystalline, fracture coarsely conchoidal, of good quality	2½

This quarry and its double east of the township line supply the southwestern portion of the county with foundation stone. Quarries have also been opened in the vicinity of Raymond in section 36, township 88 north, range XII west. Their chief interest comes from the fact that this is one of the classic sections in the correlation of Devonian deposits in Iowa and not on account of its economic importance. The quarries have been but little worked for many years and the sections are much obscured.

LIME.

Black Hawk, like numerous other limestone counties, produced lime to supply its own needs in its early history when wood was cheap and transportation facilities poor. The industry was never of more than local importance and has long since been abandoned, although the sub-crystalline beds at Laporte and other points would undoubtedly produce a good grade of lime.

BREMER COUNTY.

The Wapsipinicon and Cedar Valley stages are well represented in Bremer county. Beds of the latter age are supposed to occur immediately beneath the drift over more than five-sixths of the county, while known outcrops of the former are limited to points along the Cedar river from Janesville to Waverly, and along Quarter Section run and Baskin creek southeast of Waverly. The best section available appears in the southeast quarter of the southwest quarter of section 20, township 91 north, range XIII west. The beds exposed are as follows:

		FEET.
6.	Limestone, massive, in one undivided layer weathering to scoriaceous surface in places and in other places to smooth surface. Color mottled, prevailingly a light brownish drab, weathering to lighter gray, slightly vesicular, fracture uneven	4
5.	Limestone of same facies as above in layers of about eight inches	2
4.	Concealed	15
3.	Limestone similiar to Nos. 5 and 6, but in separable laminæ	1
2.	Cherty sandstone; in layers from four to six inches thick, chert fragments angular, small, those of an inch and one-half being rare, sand fine, of moderately well rounded grains of clear quartz and of minute, angular grains of cryptocrystalline silica, cement calcareous. Not seen in place but scattered in slabs over a slope of	5
1.	Niagara limestone, exposed a few rods down stream	8

The limestones are essentially pure as evidenced by the analysis given herewith:

Silica (SiO_2)	.71
Ferric oxide (Fe_2O_3) Alumina (Al_2O_3)	.46
Calcium carbonate ($CaCO_3$)	96.57
Magnesium carbonate ($MgCO_3$)	1.80
Combined water (H_2O)	.51
	100.05

The Wapsipinicon beds are not worked to any noteworthy extent at the present time. The Cedar Valley on the other hand is being or has recently been quarried at four leading localities, Janesville, Waverly, Frederika and along the Cedar river north of Plainfield. With a single exception the individual quarry output is small. The sections given below will afford a fair idea of the potential wealth of the county in structural materials. The beds developed in Mores' quarry located on the left bank of the Cedar in the town of Waverly are as follows:

MORES' QUARRY SECTION, WAVERLY.

	FEET.
3. Limestone, yellow, fine-grained, non-fossiliferous so far as observed, heavily bedded, crossed with close diagonal joints containing numerous geodic cavities up to six inches in diameter lined with dog-tooth spar, and concretionary balls marked with reddish concentric ferruginous stains	10
2. Limestone, yellow, argillaceous, weathering above to calcareous plates one-half inch and upwards in thickness; below more massive, weathering to irregular chipstone, geodiferous, sparingly fossiliferous	8
1. Limestone, yellow, hard, tough layers up to four feet thick, fossiliferous; to flood plain of river	10

Extensive cuts along the Chicago Great Western railway one-half mile east of the station, show a yellow, profoundly decayed limestone. Underneath is a soft, buff, massive limestone containing numerous geodes. It is strongly dolomitic as indicated by the following analysis:

Silica (SiO_2)	9.07
Alumina (Al_2O_3)	2.16
Ferric oxide (Fe_2O_3)	1.21
Calcium carbonate ($CaCO_3$)	51.64
Magnesium carbonate ($MgCO_3$)	34.99
Combined water	.64
Moisture	.29
	100.00

The most important producer of quarry products is the Cedar River Stone Company, whose plant is located on the Cedar river one and one-half miles southeast of Waverly and is connected with the Chicago Great Western railway by a short spur. The quarry pit and hillside show the following beds:

		FEET.
5.	Stripping, limestone, light gray, soft, broken by the weather into layers from 2 to 4 inches thick, fossils rare	9
4.	Limestone, dense, hard, tough, yellow-gray, lowest layers about 3 inches thick, divided by diagonal joints and bedding planes into rhombic blocks 1 to 4 feet in diameter. Occasional geodic cavities an inch or so in diameter lined with drusy calcite are present; fossiliferous	25
3.	Concealed	12
2.	Breccia of Wapsipinicon stage, hard and dense	5
1.	Concealed to water's edge	3

The quarry has been developed to a depth of about thirty feet. The stone presents a clean, sub-conchoidal fracture, is almost impervious and carries but little clay. It is considerably fissured, the openings are often large and filled with a clay of putty-like consistency of gray to gray-blue color when freshly exposed but iron-stained where weathered. The quarry drains directly into the river. At present there is but little stripping, the removal of which is done by hand. The quarry is ideally located for the installation of a hydraulic plant for removing the overburden.

Practically the entire product of the quarry is crushed stone of excellent quality. An elaborate system of tracks connects the different parts of the quarry to the foot of the incline leading to the crusher. The stone is loaded into side dump cars of about one and one-half yards capacity, and these are trammed by hand to the foot of the incline where they are raised to the floor of the crushers by an Austin friction hoist. The rough quarry stone is dropped directly into the hopper of a number 7½ Austin gyratory crusher. The crushed stone is hoisted and delivered to a cylindrical screen where it is separated into dust, middlings and large, the oversize returning to a number 5 Austin crusher for further reduction, after which it is discharged directly into the crushed product from the large crusher. The plant is supplied with ample storage bins and side tracks. Rail-

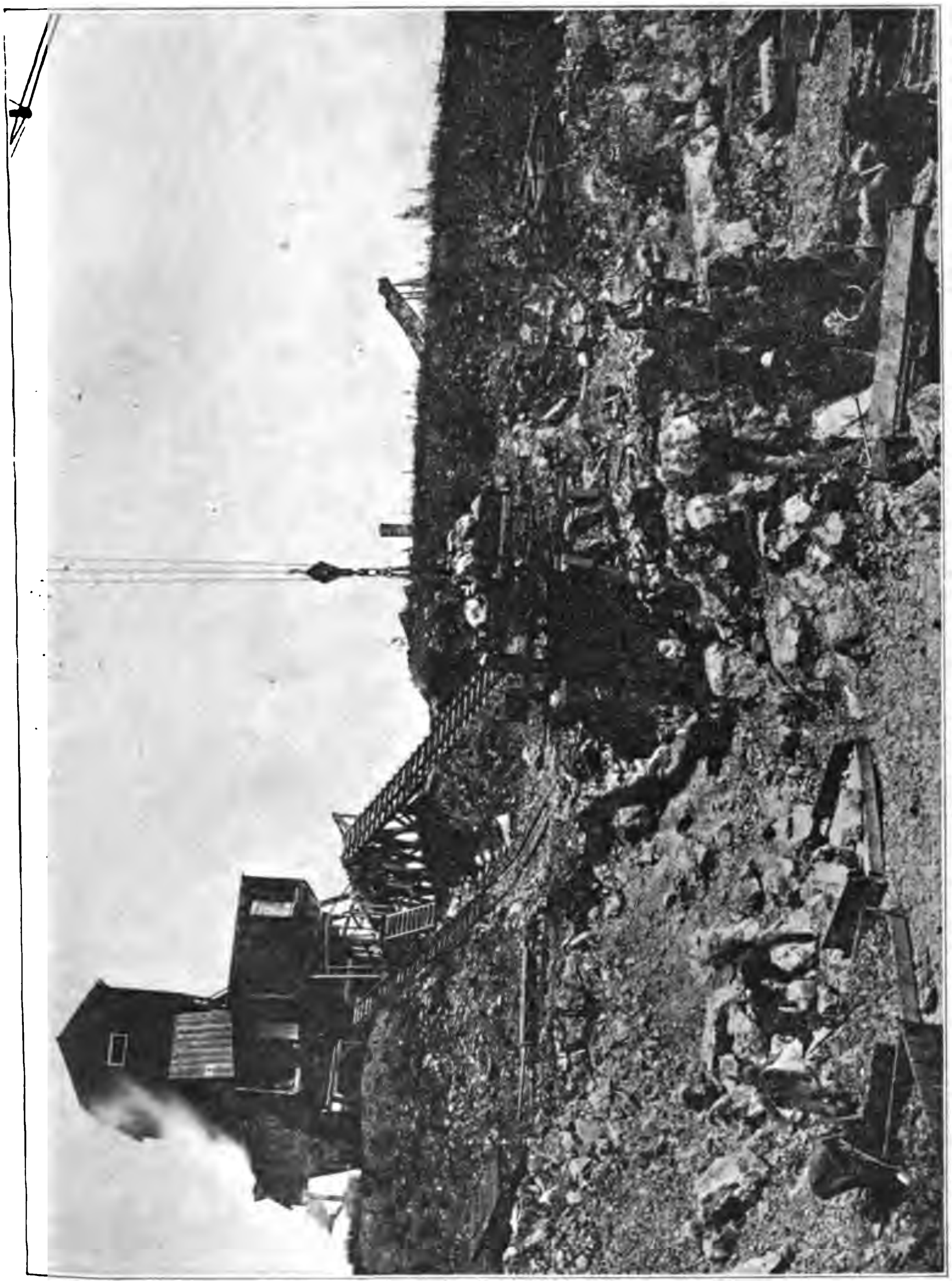

PLATE XLV—Quarry and crusher plant of Cedar River Stone Company, near Waverly, Bremer county, Iowa. The quarry stone is brought to a platform at foot of an inclined plane leading to crusher. The irregularly bedded stage of the Devenian is well shown in the quarry.

way track scales are installed below the chutes leading from storage bins. Power is supplied by a dismounted railway locomotive boiler and a 125 horse power, slide valve engine. The power is transmitted by a single line shaft and comparatively short belts. The entire equipment is well housed and the plant is one of the largest and most up-to-date plants in the state.

North of Waverly the limestone outcrops at numerous points on both sides of the river to the north county line. On the southwest quarter of section 16 in Lafayette township the following beds may be made out:

		FEET.
3.	Limestone, light brown, weathering to drab, hard, ringing, unfossiliferous, laminated to plates one-half inch thick	8
2.	Limestone, magnesian, soft, buff	10
1.	Unexposed to flood plain of river	5

North of Plainfield, several small quarries have been opened. Seven feet of buff, compact, magnesian limestone, in layers from six to ten inches thick, and containing irregular concretions, have been quarried. The beds are thin and argillaceous for a few inches at the top. An analysis has been made of the rock quarried in section 8, with the following results:

Silica (SiO_2)	3.28
Ferric oxide (Fe_2O_3)	1.61
Alumina (Al_2O_3)	.51
Calcium carbonate ($CaCO_3$)	55.23
Magnesium carbonate ($MgCO_3$)	39.03
Combined water	.23
Hygroscopic water	.16
	100.05

East of the Cedar river and immediate vicinity the country rock is deeply covered with drift, and the only exposures of the indurated beds are in the immediate neighborhood of Frederika along the Wapsipinicon river, and a limited outcrop of Niagara limestone west of Tripoli.

At Frederika the drift covering is comparatively thin and the limestone bears evidence of considerable superficial weathering in the enlarged joints and limestone residuum. The Brodie quarry facing the Wapsipinicon is a fair average for the district. The following beds may be observed:

	FEET.
3. Limestone, yellow, shattered by the weather to coarse rhombic chipstone	9
2. Limestone, hard, yellow, magnesian, in heavy courses up to three feet thick, not laminated; bedding planes quite even and regular, geodes up to six and eight inches in diameter not uncommon	6
1. Limestone, bluish weathering to buff; hard, ringing, sub-conchoidal fracture, in two layers, the lower being one foot and the upper two feet thick. Sparingly fossiliferous	3

LIME.

Lime is produced in a small way at Frederika. The buff magnesian limestone of the Cedar Valley stage as developed in the Brodie quarry is used. A small, wood burning pot kiln is employed, and a good grade of lime is produced. Lime has also been produced northeast of Waverly and north of Plainfield. At the former place the Niagara limestone was used and an excellent grade of lime produced. The kilns are no longer in operation at these places.

BUCHANAN COUNTY.

Beds belonging to the Devonian are found immediately beneath the mantle of drift over about two-thirds of the superficial area of the county. The remaining one-third is occupied by the Niagara in the form of a triangle in the northeast corner. The lowest Devonian beds which afford any quarry products, are represented by a rather soft, imperfectly bedded limestone, which, as a rule, yields readily to weathering influences. It is very much shattered and jointed, and has been referred to the Wapsipinicon stage of Norton. A number of small quarries have been opened in the beds in the vicinity of Independence. Along Pine creek in Liberty township, and on sections 33 and 34 in Newton township, the equivalent beds are harder and generally better in quality. An average section for Independence is taken from a quarry located in the eastern edge of town and is as follows:

	FEET.
3. Limestone, yellowish, rather hard, rings when struck with the hammer, in rather thin layers, and containing numerous corals, among which *Cystiphyllum americanum* and *Acervularia profunda* are the most characteristic species	4

	FEET.
2. Limestone, the *Spirifer pennatus* beds, showing the usual assemblage of fossil species, not definitely bedded, but intersected by a great number of joints. The phenomenon of "slickensides" is developed on the joint faces on an extensive scale....................................	8
1. Limestone, the barren beds, lithologically like the *S. pennatus* beds above..	10

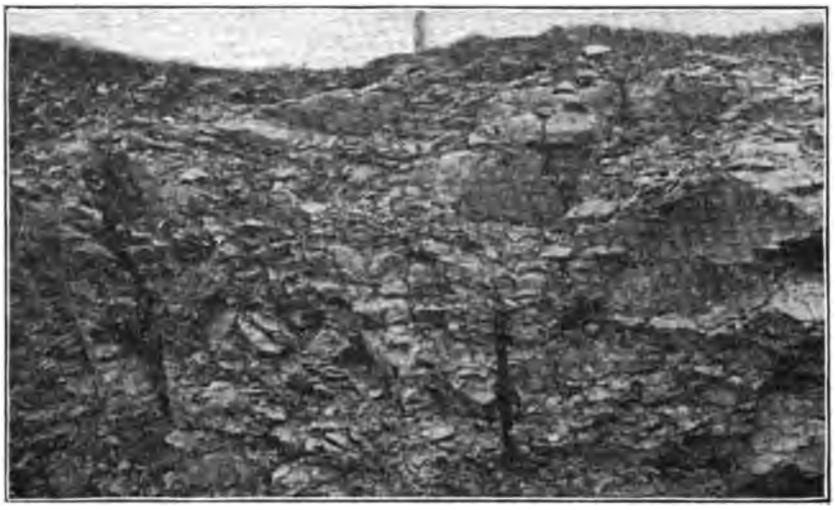

FIG. 22—View in City quarry at Independence showing effect of crushing in the *Spirifer pennatus* beds, upper part of brecciated zone.

No. 3 of this section is the lowest member of the Cedar Valley stage of the Iowa Devonian.

Similar sections may be observed along Pine creek and the Wapsipinicon in Liberty township. Also along Dry creek in Newton township.

The most important quarries have been opened in the Cedar Valley limestone. The stone is harder, resists weathering influences better and occurs in more regular beds than the Wapsipinicon. These beds have been developed at Fairbank, near Littleton, Jesup, and Brandon, and near Quasqueton, where a small outlier of the Cedar Valley occurs some miles from the main body. The beds quarried are about the same at all of these places.

At Fairbank a quarry in the west side of the river shows the following beds:

		FEET.
5.	Very dark brown residual clay or geest; a few inches to	1
4.	Limestone, in thin layers	4
3.	Limestone, fossiliferous	1
2.	Limestone, yellowish, soft, evenly bedded, in layers ranging up to six or eight inches in thickness	5
1.	Limestone, heavy beds, not fossiliferous, exposed at base of quarry	2-3

Farther south more extensive sections are shown. At Littleton extensive natural sections aggregating seventy feet, may be seen both above and below the dam. Here is one of the classic sections in the county, but it is of little economic importance. Only the uppermost beds have been quarried, two small quarries having been opened north and northwest of town on top of the bluffs. The beds worked consist of a yellow, earthy limestone, occurring in even layers varying from two to eight inches in thickness. Nearly twenty feet is exposed in the quarry face.

At Jesup there are two quarries, one on each side of the correction line road, one-half mile southeast of town. The north quarry shows the following section:

JESUP SECTION.

		FEET.
6.	Black loam	1-2
5.	Limestone, yellow, broken and decayed, more or less disturbed	2-3
4.	Limestone, yellowish, not very fossiliferous, affords some good quarry stone	5
3.	Limestone, soft, easily affected by the weather	2
2.	Limestone containing numerous stromatoporoids and true corals. Some fair building stone	6
1.	Limestone, fissile, with few fossils	3

The strata dip slightly toward the east and are somewhat contorted. At the quarry south of the road the upper beds are worked and dip slightly to the south. The beds quarried at Quasqueton are very similar to those exposed at this point.

Several small quarries have been opened along Lime creek in the vicinity of Brandon and for several miles to the northeast. Just south of Brandon near the north line of section 34 the following section is exposed:

BRANDON SECTION.

		FEET.
4.	Limestone, soft, grading up into yellow shale, which carries silicified brachiopod individuals	8
3.	Coral reef consisting of Acervularia, Favosites, Ptychophyllum and other corals	1
2.	Limestone, evenly bedded, with few fossils or none	4
1.	Limestone, regularly bedded, and capable of being quarried, in layers from two to 6 inches in thickness, the thinner beds serving well as flagging	4

While the Devonian is capable of supplying an indefinite amount of fairly good structural material, but little quarrying has been done, and that for local use only.

LIME.

Formerly lime was produced at several points; notably at Independence and Quasqueton from the Devonian limestone and in section 19 of Madison township, where the Niagara limestone was used. No lime was produced during 1906.

BUTLER COUNTY.

The Devonian is believed to immediately underlie the drift over nearly, if not all of the county. Stone crops appear along the principal streams at numerous points, especially along Shell Rock river and its immediate tributaries. Outcrops may be noticed along the Illinois Central between Ackley and Austinville; along the Northwestern between Kesley and Dumont; along the Great Western between Dumont and Bristow, and from near Clarksville to Shell Rock and beyond.

Between Dumont and Bristow some quarrying has been done. The stone may be seen in street crossings and foundations in both Dumont and Bristow. The beds range from six to ten inches in thickness and can be taken out in almost any length and width. All of the stone is hard and compact and splendidly adapted to crushed stone purposes. The quarries are not in operation at present.

Along the Shell Rock river small openings appear in the bluff on the east side of the river and a small quarry is being operated about three and one-half miles northwest of Clarksville. The section exposed in the pit is as follows:

		FEET.
3.	Soil and drift of variable thickness........................	1-3
2.	Limestone, yellow to brown, magnesian to dolomitic, in thin layers, evenly bedded....................................	6
1.	Limestone, white to gray, hard, brittle, evenly bedded, compact to lithographic; certain of the layers show fossils in weathered surfaces but these are firmly bedded and do not show in fresh fractures, exposed..........................	7

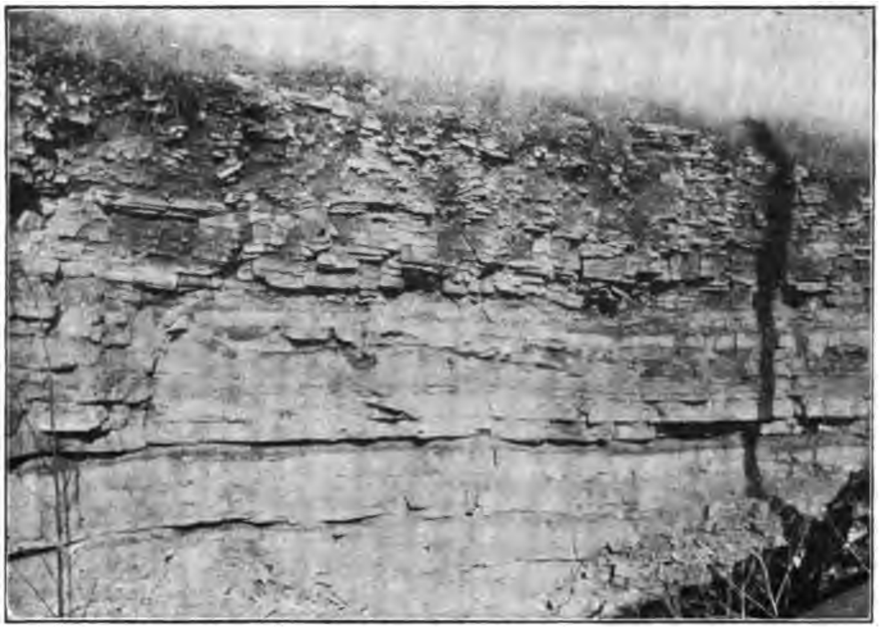

FIG. 23—Schrader quarry, Clarksville, Butler county, Iowa, showing the flaggy, lithographic facies of the Cedar Valley.

The beds exposed here are very similar to those which are exposed at Marble Rock in Floyd county and correspond to the two lower members in the section at that place. Equivalent beds are, however, somewhat thinner and the shaly partings are rather more pronounced, perhaps due to more advanced weathering. The brecciated layer near the top of the white limestone is equally as prominent as in the Marble Rock section. A similar sequence may be made out in the openings near Greene. Small quarries have been opened near Shell Rock. Both white limestone and the dolomitic layers have been used quite generally throughout the eastern portion of the county for foundation purposes and formerly for the walls of some of the less important buildings. Both, when properly selected, give good service and appear to be fairly durable.

The limestone has also been used for flagging; blocks six to ten inches in thickness and of almost any dimensions in length and breadth can be obtained quite readily. The white limestone throughout is very hard and compact and admirably adapted for crushed stone purposes. The stone can be obtained at several places without much stripping but as yet the industry can scarcely be said to have been started.

Lime in small amount was produced formerly at several places but no lime has been burned for many years.

CEDAR COUNTY.

Beds of Devonian age cover a large triangular area over the southwest fourth of the county and numerous outcrops are to be seen along the Cedar river and its more important tributaries, Rock and Sugar creeks, often showing the Niagara beds below. Notwithstanding the availability and large areal distribution of these beds they are over-shadowed in importance by the Niagara and are of local importance only. The only producers are small quarries on the west bank of the Cedar in Iowa township near the Muscatine county line. The quarry section is given below.

		FEET.
4.	Limestone, hard, compact, gray and buff, mottled, in layers from 2 to 4 inches thick, overlain with red geest	1½
3.	Limestone, shaly, yellow	½
2.	Limestone, yellowish drab, splitting into irregular layers, from 2 to 6 inches thick	3
1.	Limestone, tough, hard, gray, evenly bedded, resistant to weathering, in two or three layers	3½

About thirty-five feet above the base of the hill layers of a comparatively barren limestone have been opened up. In the five feet here exposed no fragments large enough to identify were found. The stone is yellow, breaking up into chipstone.

No lime of any consequence is now made from Devonian rocks in Cedar county.

CERRO GORDO COUNTY.

Beds of Devonian age are believed to occur immediately beneath the drift over the entire county, with the exception of a triangular area in the southwest corner. Two distinct substages may be readily recognized, the lower beds, which are prevailingly calcareous or dolomitic and highly indurated, often sub-crystalline, and an upper series which is made up of shales and marls with occasional indurated ledges. The first belongs to the Cedar Valley stage of the Devonian, of which the upper portion only is represented in the county, while the latter belongs to the Lime Creek shales of the Upper Devonian series. The principal outcrops of the Cedar Valley limestones occur along Lime creek and the Shell Rock river and their immediate tributaries. All of the quarries in the county which are of more than local significance are developed in this stage. From an economic standpoint the Cedar Valley beds may be separated into four groups more or less readily recognized. The sequence is as follows, from top downwards:

		FEET.
4.	Limestone, exceedingly variable in texture, structure, and composition, ranging from a granular, sub-crystalline dolomite, through magnesian limestone and argillaceous limestone, to pure limestone. The beds thicken and thin out in short distances. In places lamellar stromatoporoids are present in lower beds	25+
3.	Limestone, a well-marked reef of nodular or spheroidal Stromotoporas, characteristically developed in sections in and about Mason City	8 to 10
2.	Limestone, white to light gray, hard and compact, brittle, breaks with a conchoidal fracture, evenly bedded, non-fossiliferous; in layers up to two feet in thickness, about	15
1.	Dolomite, brown, sub-crystalline, granular; generally in regular beds and but slightly porous or vesicular; thickness of individual layers and aggregate thickness variable. Earthy to calcareous and variable in composition below	20+

Numbers 1 and 2 afford all the stone used for dimension purposes. Number 3 is used for lime and is suitable for crushed stone. The principal quarries are located in the vicinity of Mason City.

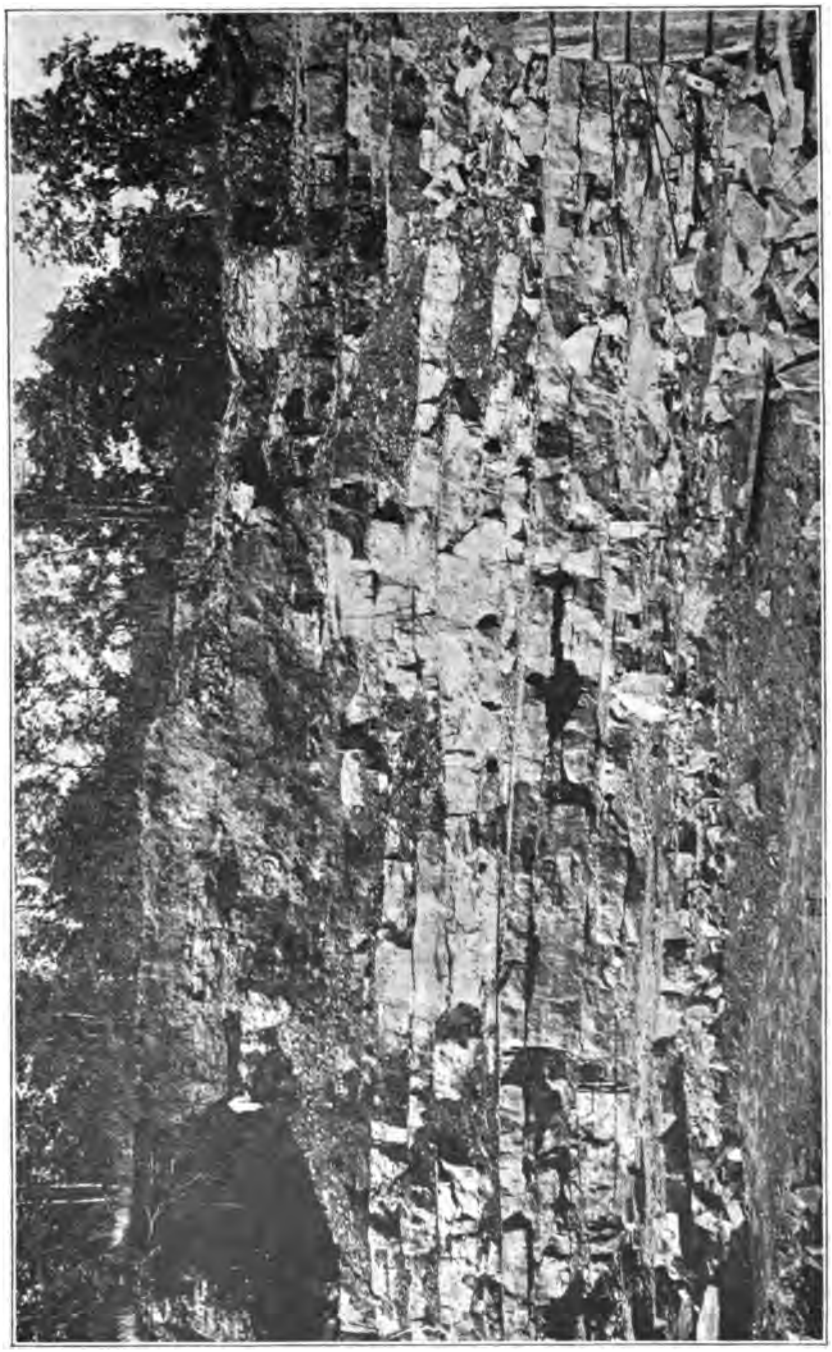

PLATE XLVI—Kuppinger quarry, Mason City, Cerro Gordo county, Iowa, showing the dolomite below, compact white limestone in the middle and the Stromatopora near the top of the section; an average section for the district.

THE KUPPINGER QUARRY.

The Kuppinger quarry, located on the east bank of Lime creek, between the bridge and the mill dam, in the northeastern part of Mason City, gives the following section:

		FEET.
7.	Residual clay and drift	4
6.	Somewhat regularly bedded stromatoporoid limestone	3
5.	Reef of stromatoporoids consisting largely of spheroidal coralla with concentric, laminated structure; some of the coralla are more than a foot in diameter. Weathers into spheroidal masses. Bedding obscure	5
4.	White or grayish, fine-grained limestone, breaking with conchoidal fracture, very compact; ledges ranging from a few inches to more than two feet in thickness. No traces of fossils, or traces few and very obscure	14
3.	Bluish limestone, flexuous and unevenly bedded	2
2.	Hard, crystalline, grayish dolomite, with occasional streaks of brown and red. In weathered portions of this member, the crystals of dolomite are in places very loosely cemented and the rock has the appearance of a friable sandstone. Some beds are vesicular, owing to the solution and removal of fossils. The cavities, however, are lined with crystals to such an extent as to obliterate all evidence of generic or specific characters. Ledges varying from 6 to 36 inches in thickness	8
1.	From floor of quarry to level of stream, covered with talus	2

The bluff slopes some fifteen feet higher than the quarry face, and is apparently supported by indurated rock. The lamellar stromatoporoids appear in detached blocks. Numbers 2 and 4 are the beds most prized for structural purposes. At the present time, the quarry is worked only intermittently, and, then in a small way. But little labor saving machinery has been installed.

Openings have been made in the bluff up stream from the Kuppinger quarry, but no new beds are exposed. The beds exposed in the quarry of the Mason City Lime and Cement Company are essentially a repetition of the above.

At Parker's Mill on Willow creek, the following natural section is exposed:

PARKER'S MILL SECTION.

		FEET.
6.	Stromatopora reef, equivalent of No. 5 of the Kuppinger quarry	4
5.	White limestone, somewhat split up by weathering	14

THE KUPPINGER QUARRY.

The Kuppinger quarry, located on the east bank of Lime creek, between the bridge and the mill dam, in the northeastern part of Mason City, gives the following section:

		FEET.
7.	Residual clay and drift	4
6.	Somewhat regularly bedded stromatoporoid limestone	3
5.	Reef of stromatoporoids consisting largely of spheroidal coralla with concentric, laminated structure; some of the coralla are more than a foot in diameter. Weathers into spheroidal masses. Bedding obscure	5
4.	White or grayish, fine-grained limestone, breaking with conchoidal fracture, very compact; ledges ranging from a few inches to more than two feet in thickness. No traces of fossils, or traces few and very obscure	14
3.	Bluish limestone, flexuous and unevenly bedded	2
2.	Hard, crystalline, grayish dolomite, with occasional streaks of brown and red. In weathered portions of this member, the crystals of dolomite are in places very loosely cemented and the rock has the appearance of a friable sandstone. Some beds are vesicular, owing to the solution and removal of fossils. The cavities, however, are lined with crystals to such an extent as to obliterate all evidence of generic or specific characters. Ledges varying from 6 to 36 inches in thickness	8
1.	From floor of quarry to level of stream, covered with talus	2

The bluff slopes some fifteen feet higher than the quarry face, and is apparently supported by indurated rock. The lamellar stromatoporoids appear in detached blocks. Numbers 2 and 4 are the beds most prized for structural purposes. At the present time, the quarry is worked only intermittently, and, then in a small way. But little labor saving machinery has been installed.

Openings have been made in the bluff up stream from the Kuppinger quarry, but no new beds are exposed. The beds exposed in the quarry of the Mason City Lime and Cement Company are essentially a repetition of the above.

At Parker's Mill on Willow creek, the following natural section is exposed:

PARKER'S MILL SECTION.

		FEET.
6.	Stromatopora reef, equivalent of No. 5 of the Kuppinger quarry	4
5.	White limestone, somewhat split up by weathering	14

		FEET.
4.	Evenly bedded dolomite, in ledges varying from 3 to 30 inches in thickness	12
3.	Impure dolomite, breaking irregularly by exposure to weather, and containing many cavities lined with crystals of calcite.	2½
2.	Crumbling, calcareous, granular bed, light gray in color, with many nodular and branching stromatopores, some favosites and beautiful coralla of *Pachyphyllum woodmani*	1
1.	Argillaceous limestone, dark drab in color, homogeneous, but breaking up on exposure to frost	2

Numbers 1, 2 and 3 appear to be lower in the series than 1 in the Kuppinger quarry.

Several companies have opened quarries north of the city. Among others are the Belden Stone Company, the Mason City Quarry Company, and the Mason City Stone Company. The last named company has recently sold out to the Northwestern States Portland Cement Company.

The sequence of beds exposed in the quarries of the Belden Stone Company is given in the following section. These quarries are located in the southeast quarter of the northwest quarter of section 27, Lime Creek township.

BELDEN STONE COMPANY SECTION.

		FEET.
7.	Soil and residual clay from a few inches to	2½
6.	White or grayish limestone, shattered into small pieces; removed as part of the stripping	3
5.	White limestone in thin layers	3
4.	White limestone in layers from 2½ to 10 inches in thickness, good building stone	4
3.	Evenly bedded dolomite, suitable for heavy walls or for cutting into caps and sills; in three ledges 21, 10 and 11 inches respectively in thickness	3½
2.	"Blue cap," a bed that quarries out in shapeless, worthless blocks, in two ledges; an impure dolomite	3
1.	Brown, bluish and gray dolomite in eight ledges, varying from 4 to 13 inches in thickness	5½

The white limestone here having less overburden is more weathered, which finds expression in its being more thinly bedded and fractured.

The beds developed by the Mason City Stone Company consist of an aggregate of nearly twenty feet of dolomite and rather more than ten feet of the white limestone.

In all of these quarries the dolomite occurs in layers of good thickness and is of excellent quality. It usually presents a more or less rough surface owing to the sub-crystalline, granular texture, and is known commercially as "Mason City sandstone." East of Mason City, the white limestone becomes much less important. A short distance below the wagon bridge at Portland, the following beds may be observed:

PORTLAND SECTION.

		FEET.
6.	Soil and wash up to	3
5.	Dolomite, coarsely granular, in thin layers	3
4.	Limestone, white with laminar Stromatoporas	2
3.	Limestone, the spheroidal Stromatopora reef, but more evidently stratified than at Mason City	4
2.	Limestone, white, evenly bedded	3
1.	Dolomite, in heavy beds	13

Up the river toward the mill, dolomitized beds higher in the series may be viewed. Numbers 1 to 4 may be correlated readily with the Mason City sections. The beds dip at a low angle down stream, and almost wholly disappear some two miles below the bridge. The "Clay Banks," beginning on the northwest quarter of section 35, present an abrupt escarpment facing the creek, and rest on the variable beds of the Cedar Valley stage which appear in the channel of the creek. While the Lime Creek shales which constitute the "clay banks" contain occasional hard ledges, they are not of sufficient importance in that connection to merit description. They will be discussed later as a possible source of Portland cement materials.

Above Mason City, the Cedar Valley limestone presents an almost continuous section along Lime creek to Fertile in Worth county. The beds display many local undulations and the usual variations in composition and texture. As a rule the beds are lower, and the main dolomite quarried in Mason City and vicinity is not well exposed. The white limestone thins materially and is oftentimes below the water line. No important quarries have been opened, although much stone has been taken out for local use.

Along the Shell Rock river the white limestone and heavy dolomite are the chief terranes exposed. Occasional very limited exposures of the beds above and below may be seen. Outcrops of the various beds appear at short intervals from Foster's mill above Plymouth to the Floyd county line. The beds as a rule are more profoundly folded than their equivalents along Lime creek. In the vicinity of Plymouth dolomitic beds prevail and are quarried to some extent. They are supposed to be the equivalents of the dolomite in the Portland section above the stromatoporoid zones. The beds rise down stream. At Rock Falls beds much lower in the series appear. Below the wagon bridge, the following section is exposed:

		FEET.
5.	Drift and waste almost nothing	
4.	Limestone, white	1-3
3.	Dolomite, in regular beds and of good quality	16
2.	Dolomite, impure and irregularly bedded, becoming nodular on weathering	3
1.	Dolomite, argillaceous	3

The lower beds in the above section are almost identical with those exposed in the Parker's Mill section in Mason City. Numbers 1 to 3 are better seen in Vermilya's bluff on the northeast quarter of section 35 in Falls township, where they show a maximum exposure of forty feet. The lower twenty feet show no definite bedding planes and the rock breaks up into angular pieces by weathering. While the beds are more or less continuously exposed for some distance, no new phases are shown within the confines of the county. While quarries might be opened at almost any point, none worthy of individual mention are in operation.

LIME CREEK SHALES.

While the Lime Creek shales as developed in Cerro Gordo county comprise essentially clay shales and marls, occasional indurated ledges are present, especially in the upper member or Owen beds. These hard layers are quarried at several points in Portland, Owen, Geneseo and Dougherty townships. The stone developed is usually a rather soft, yellow, earthy dolomite of fair to poor quality, and is of local importance only.

The shales and marls promise to be of far greater importance in the manufacture of Portland cement. The most important section exposed in the county may be viewed on section 35 in Portland township, facing a convex bend in Lime creek and continuing a distance of about a mile. The beds exposed are as follows:

CLAY BANK SECTION.

		FEET.
6.	Soil and drift, almost a neglectable quantity	
5.	Shale, calcareous or marl; in some places indurated layers appear	3
4.	Cap rock, variable in thickness	1
3.	Marl, highly fossiliferous; containing occasional hard bands	20
2.	Shale, non-fossiliferous, weathered yellow	10
1.	Shale, bluish gray to blue and becoming highly plastic on weathering; non-fossiliferous	40

A hard compact limestone outcrops in the creek and forms the floor upon which the above section rests.

Samples selected from this section were analyzed; the results are given in the table below, the numbers corresponding to the numbers in the section. Three samples were selected from the marl comprising number 3 in the section, of which 3a was taken from the indurated layers.

Analysis of clay shales and marls from the "Clay Banks" near Portland, Cerro Gordo county.

	No. 1	No. 2	No. 3	No. 3a	No. 3b	No. 4	No. 5
Moisture	1.21	1.00	0.73	0.35	0.75	0.68	0.93
Combined water	3.29	0.76	2.72	0.17	3.67	2.44	2.04
Silica	49.93	50.15	20.26	5.36	20.82	7.59	27.26
Alumina	20.23	19.68	11.28	3.79	11.55	5.62	19.15
Ferric oxide	4.32	4.08	2.76	1.20	2.76	1.56	4.32
Lime	6.70	9.78	31.42	48.18	30.01	44.34	16.47
Magnesia	2.79	2.26	3.44	2.70	4.01	3.22	2.23
Sulphur trioxide	1.14	1.18	2.09	1.02	1.19	0.51	1.11
Soda	2.17	1.03	0.50	0.27	0.72	0.29	1.55
Potash	2.25	1.62	1.09	0.46	1.41	0.48	2.20
Carbon dioxide	6.05	8.54	23.56	35.73	23.05	33.39	12.59

J. B. WEEMS, Analyst.

The stripping is of variable thickness but usually unimportant. The marly beds 3 to 3 b have almost the proper composition for a Portland cement and merit more attention than has been given them. The above section is about equally distant from the Iowa-Dakota division of the Chicago, Milwaukee & Saint Paul and the Fox Lake division of the Chicago and Northwestern railways.

At Mason City, the shales and marls appear some distance to the south and west of Lime creek while there is an almost continuous section of limestone along Willow, Calamus and Lime creeks.

The shales and marls are exposed south and west of the city. Immediately west of the fair grounds, along a small creek, the following section is exposed:

		FEET.
2.	Marl, weathered yellow	12
1.	Shale clay, blue-gray, becoming very plastic when weathered, exposed	20

The shales are known to attain a thickness of some forty feet southwest of the city in the pits of the brick companies. Analyses were made of all of the members in the above sections and the results are given below.

	1	2	3	4	5	6
Silica	35.23	54.56	51.95	0.72	0.63	54.64
Alumina Ferric oxide	21.09	30.62	18.34 7.56	0.91	0.71	14.62 6.45
Calcium carbonate	32.84	4.10	4.14†	94.22	97.48	9.21
Magnesium carbonate	3.94	2.13	3.26†	1.32	0.99	6.09
Alkalies as K_2O	....	2.32	4.12	....	....	5.89
Sulphur trioxide	3.11	2.30	2.76	0.98	....	....
Combined water	4.26	4.19	7.49*	2.46	....	3.74
Moisture	0.12	0.30	0.42	0.05	0.51	0.85

* Combined water and carbon dioxide.
† These percentages are of oxides instead of carbonates.

1. Marl from exposure west of fair grounds.
L. G. MICHAEL, Analyst.
2. Shale from exposure west of fair grounds.
L. G. MICHAEL, Analyst.
3. Shale from pit of American Brick and Tile Company.
J. B. WEEMS, Analyst.
4. Stromatopora limestone, quarry of Mason City Lime & Cement Company.
L. G. MICHAEL, Analyst.
5. Mason City White Limestone, quarry of Mason City Lime & Cement Company.
A. O. ANDERSON, Analyst.
6. Shale from pit of Mason City Brick and Tile Company.
G. E. PATRICK, Analyst.

The marls and shales are known to extend over a large area and are easily reached, as there is but little cover over them.

They can be traced with little interruption from the exposures west of the fair grounds in Cerro Gordo county to several miles south of Rockford in Floyd county.

All of the shales are calcareous and grade insensibly into marls.

CHICKASAW COUNTY.

The Devonian limestones are believed to comprise the surface country rock over the entire county, with the chief sections exposed along the most important streams, especially in the western tier of townships. According to Professor Calvin, the beds are more or less magnesian throughout the entire series exposed, some of the beds being so completely dolomitized as to resemble certain phases of the Niagara limestone in Delaware and Dubuque counties. The predominating facies is a soft,

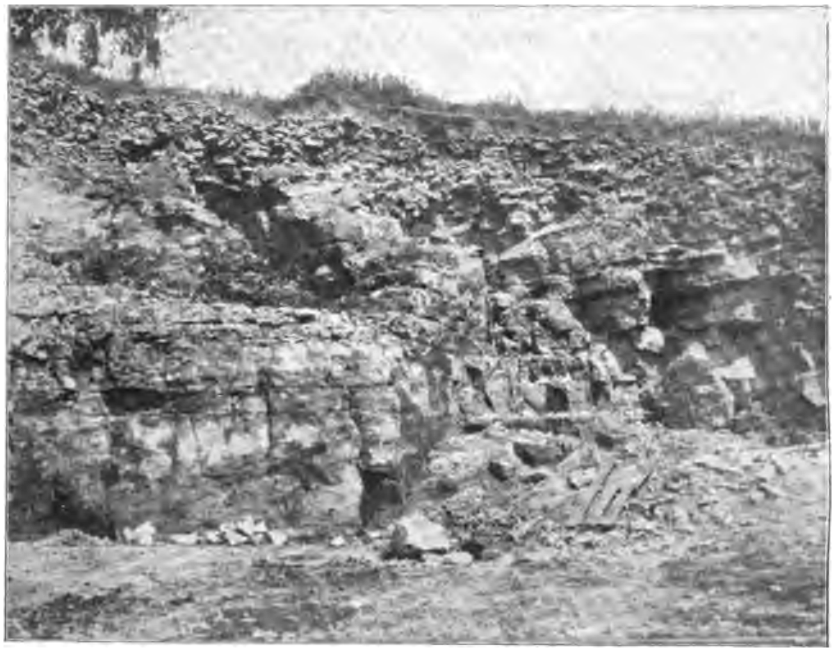

Fig. 24—Quarry in cherty dolomitic beds at the *Gypidula comis* horizon a short distance above the bridge at Chickasaw

earthy to granular, non-crystalline limestone, oftentimes cavernous. Crystalline calcite geodes are not uncommon. Rough stone for local use only has been taken out from time to time at numerous points in the county, and lime has been burned on a small scale until recently, in the vicinity of Chickasaw.

The section located near the wagon bridge in Chickasaw shows twenty-five feet of heavy bedded dolomite, which is much broken toward the surface on acount of weathering. Lower down the beds are intersected by numerous joints. A large amount of chert in streaks and bands is a striking feature of this section, and one very unusual in the Devonian.

A section which occurs about one mile north of Chickasaw, illustrates a flaggy facies of the Devonian. The stone as usual is highly magnesian and occurs in thin, even layers, varying from two to six inches in thickness. There are numerous calcite lined caverns and some very perfect calcareous geodes present.

A fairly representative section showing the variable character of the Devonian beds as developed in the county, is exposed in the southeast quarter of section 3, Deerfield township. The sequence is as follows:

		FEET.
7.	Loam and drift	2
6.	Limestone, thin-bedded, earthy and badly weathered	3
5.	Limestone, hard ledge; drab colored, purer and more crystalline than 4 and 6	½
4.	Limestone, thin-bedded; becomes marly and concretionary on weathering	2
3.	Shale, arenaceous, yellow and plainly laminated	4
2.	Limestone, hard, dark gray, layers six to ten inches in thickness and now forms floor of the quarry	2
1.	Limestone, hard, not now exposed, but was quarried formerly	3

It is evident from a casual inspection of the above section that the overburden of drift and worthless material is practically prohibitive. While certain ledges at numerous other points yield excellent structural material and stone of suitable composition for a good quality of lime, the high proportion of waste which must be handled makes a large production improbable.

FAYETTE COUNTY.

Indurated rocks of the Devonian immediately underlie the drift over the middle and western portions of the county, constituting one-half of its superficial area. Outcrops are limited to the immediate vicinity of the streams on account of the great thickness of the drift, especially over the west portion of the county.

Quarries have been opened at a number of points, notably in the town of Fayette, in the northwestern corner of Windsor township, near the towns of Alpha and Waucoma in Eden township and near Fairbank and Maynard in Oran and Harlan townships respectively. The quarries are of small capacity and supply only the local demand.

The Westfield bridge section, which is located on the northeast quarter of section 29 in Westfield township, is one of the most extensive Devonian sections in the county and shows the Devonian contact with the Niagara. The sequence of beds is as follows:

		FEET.
9.	Limestone, much weathered, in thin fragments, fossiliferous.	1
8.	Limestone, yellow, impure, fine-grained; in layers two to six or eight inches in thickness..............................	5½
7.	Limestone, yellow, impure, in three heavy beds.............	7
6.	Limestone, yellowish gray, rather massive, less magnesian than number 7 above and somewhat broken...............	8
5.	Limestone, argillaceous, light colored, consisting of brecciated material in which small limestone fragments are imbedded in a clayey shale matrix.........	7
4.	Limestone, brecciated; composed of dense, fine-grained drab colored fragments of limestone, surrounded with lighter colored cementing material........	10
3.	Limestone, yellowish gray, very fine-grained; weathers into thin fragments..	11
2.	Limestone, yellow, magnesian, in two ledges, the upper dense, rather fine-grained, one foot thick, and the lower softer, vesicular, two feet in thickness...........................	3
1.	Limestone, yellowish, magnesian, heavily bedded, cavernous, cherty and fossiliferous..................	22

In the above section numbers 1 and 2 belong to the Niagara. The balance of the section belongs to the Devonian. The upper beds only are quarried in and about Fayette and their equivalents are quarried near Fairbank and Maynard, but at the latter localities the beds have become much less magnesian and as a consequence do not afford as durable structural material as the same layers at Fayette.

In the northwest quarter of section 6, Windsor township, the following beds are available:

		FEET.
6.	Limestone, residual	1
5.	Limestone, magnesian, yellow, in layers two to six inches in thickness. The layers are much shattered	6
4.	Limestone, yellow, fine-grained, earthy, in layers six inches to two feet in thickness; somewhat nodular	3½
3.	Limestone, yellow, impure, resembling number 4; in layers eight to thirty inches in thickness, somewhat fossiliferous	6
2.	Limestone, yellowish gray, in rather indistinct layers which are checked by numerous joints, fossiliferous	8
1.	Shale, light colored, containing occasional fragments of limestone. Shale fragments become more abundant in lower parts; talus covered to bed of stream	7

Similar sections appear at other points in the neighborhood. Beds higher in the series than those in Windsor township are quarried in the town of Fairbank in the southwest corner of the county. The quarry section is as follows:

		FEET.
5.	Soil, drift and residual materials	5
4.	Limestone, yellow, much decayed, in thin layers, fossiliferous	2½
3.	Limestone, hard, gray, in thin layers, fossiliferous	2
2.	Limestone, yellowish gray in rather even layers with occasional bands of shaly material; showing numerous spots of concentrically arranged lines of iron stains; fossiliferous.	6
1.	Limestone, gray, massive, containing numerous geodes of calcite and bearing but few fossils	3

Other quarries have been opened in the neighborhood but developed nothing new. The quarries in the vicinity of Maynard are less extensive than those at Fairbank and show no new phases.

FLOYD COUNTY.

The Devonian limestone and shales form the country rock over the entire county so far as known at this time. Numerous outcrops appear along the Shell Rock river, Floyd creek, the Cedar river and the Little Cedar river. Outcrops of the Lime Creek shales are confined to Rockford and vicinity, while all of the limestones belong to the Cedar Valley stage. The limestones are prevailingly hard, white, compact, often lithographic, evenly bedded and almost pure calcium carbonate. They are often associated with or interbedded with magnesian or dolomitic layers.

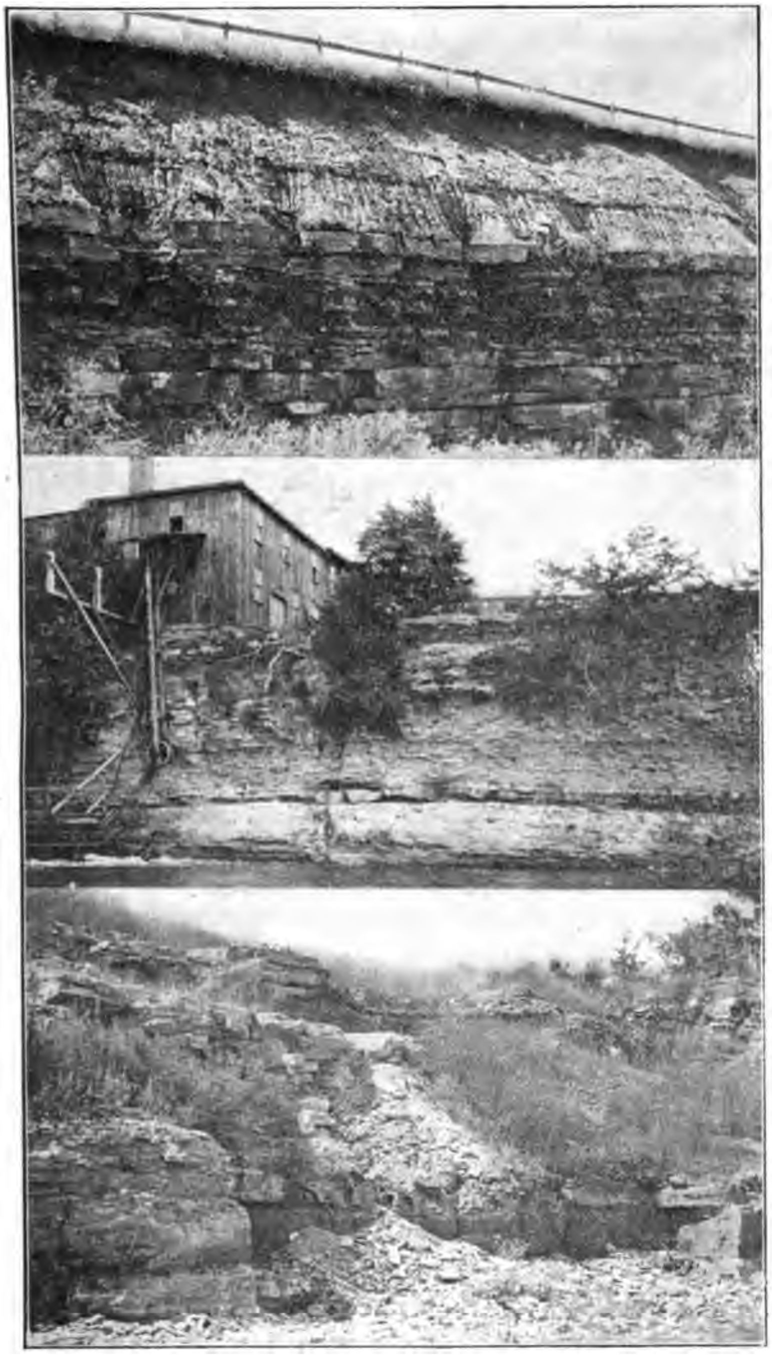

Plate XLVII.—a. City quarry, Charles City, Floyd county, Iowa.
b. Shell Rock river, Nora Springs, Floyd county, Iowa.
c. Floyd quarry section.

Along the Shell Rock river, sections at Nora Springs, Rockford and Marble Rock give the range of beds which may be observed. At Nora Springs the following beds appear in the bluff at the foundry about one hundred and fifty yards up stream from the Milwaukee railway bridge.

		FEET.
7.	Soil and drift of variable thickness	1-4
6.	Limestone, coralline zone, colonies very much flattened, bedding planes not very distinct	6
5.	Limestone, buff to gray-buff, otherwise similar to number 4; bedding planes rather more apparent	4
4.	Limestone, white, much shattered, compact and brittle; bedding planes not apparent	3+
3.	Limestone, spheroidal Stromatopora zone; appears to be decidedly concretionary where weathered, spheroids up to 10 inches, horizontal diameter somewhat the larger	8
2.	Limestone, gray-buff, evenly bedded, compact to somewhat earthy fracture, less brittle than 1, grades upward into white limestone	2
1.	Limestone, white, apparently brecciated; bedding planes not well defined, compact and brittle, exposed at this point above low water	6

Just below the mill, some three-eighths of a mile farther up stream, several small quarries have been opened. The same beds are exposed but show considerable variations, especially in bedding. All of the beds up to number 4 are massive. Number 2 appears as a single ledge, in places. Although the spheroidal masses can be seen, number 4 takes on a somewhat shaly character and is thicker than at the foundry. In places, however, this member appears as a single massive ledge. The beds all dip up stream. The stone derived from these beds is used quite generally throughout the town and adjoining country.

At Rockford, beds higher in the series appear and only the uppermost member of the Cedar Valley limestone appears in the low escarpment along the river. Back from the river the Lime Creek shales appear. While the actual contact between the Cedar Valley and the Lime Creek was not seen, the section which can be viewed along the river and in the pit of the Cream City Brick and Tile Company is as follows:

ROCKFORD SECTION.

		FEET.
10.	Soil and drift, variable in thickness	0–2
9.	Marl, blue-gray, oxidizes to a yellowish color, highly fossiliferous	12+
8.	Clay-shale, gray-blue, slightly gritty and more pervious than beds below	15
7.	Iron-stained zone, containing concretions; of variable thickness 6 inches to	2
6.	Clay-shale, similar to number 5	6
5.	Shale, gray-blue, slightly gritty	12
4.	Limestone, shaly, exposed but thickness not determined	
3.	Limestone, white, similar to uppermost beds along the river at Nora Springs; coralline, thinly bedded	12
2.	Dolomite, or dolomitic limestone, brown and porous	3
1.	Limestone, gray-blue, in medium heavy ledges, exposed	4

The marls and shales continue more or less uninterruptedly to the "Clay Banks" south of Portland in Cerro Gordo county and can be traced southward from Rockford two or three miles. They are not known to occur in any considerable quantity north and east of Lime creek or the Shell Rock river. The marl is used to some extent for road work and appears to cement well. The lower limestone beds have been quarried in a small way but are too near the water level in the river to permit their extensive development.

At Marble Rock a number of quarries have been opened and are operated at the present time. About three-fourths of a mile above the wagon bridge a quarry has been opened on the east side of Shell Rock river and presents the following beds:

MARBLE ROCK SECTION.

		FEET.
5.	Soil and drift	1–4
4.	Limestone, white, with spheroidal Stromatopora, hard and brittle, beds heavy where unweathered; becomes cavernous in part and the middle portion is brecciated, exposed	10–12
3.	Limestone, magnesian or dolomitic, much weathered and stained in places, yellowish brown, evenly bedded, ledges shaly in part	8
2.	Limestone, dolomitic, shaly, iron-stained	2
1.	Limestone, white, the details are as follows: 10 inch ledge, lithographic. 10 inch ledge, brecciated. Two 10 inch ledges, separated by shaly parting. 10 and 12 inch ledges, lithographic in character. 20 to 24 inch ledge almost lithographic. 14 inch and 18 inch ledges, separated by shaly parting, hard, compact.	
	Total	9

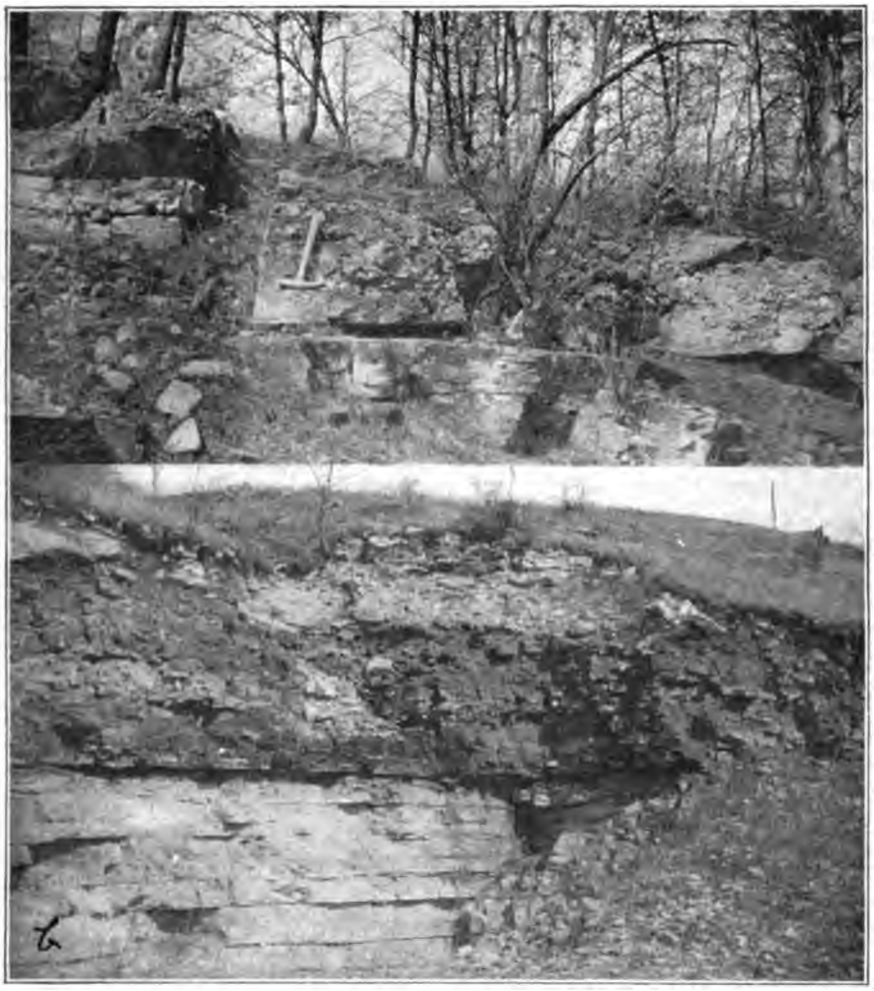

PLATE XLVIII.—a. Old lime quarry above Marble Rock, Floyd county, Iowa, showing Stromatopora zone and brecciated zone.
b. Marble Rock quarry showing evenly bedded, lithographic beds below, and Stromatopora and brecciated zone above.

The ledges in number 1 constitute a compact, hard, brittle limestone almost lithographic throughout, with the exception of the ledge next to the top of the series, which is distinctly brecciated. All of the layers are evenly bedded and all but the third and fourth layers are separated by shaly or marly partings, thus facilitating quarrying by very simple methods. All of the lower limestone beds show good ability to resist weathering influences. The lower limestone beds are most highly prized for quarry purposes although the dolomitic beds, when not too much weathered, are also used. Both the upper and lower limestones are well adapted for crushed stone products. Old quarries were opened in the upper limestone, which was also burned for lime. The remains of an old pot kiln may still be seen in the immediate neighborhood.

Along the Cedar river and its immediate tributaries an abundance of indurated rock is available, often with very little overburden. The principal quarries are located at Lithographic City, Floyd and Charles City. The Interstate Development Company has made extensive openings at Lithographic City and is planning to operate its property on a large scale in the near future. Two quarries have been opened. The beds exposed are as follows:

LITHOGRAPHIC CITY SECTION.*

		FEET.
11.	Soil and drift	1
10.	Limestone, lithographic	5
9.	Limestone, yellow-gray, friable, coarsely granular and thin-bedded	⅓
8.	Limestone, dense, compact, buff to grayish white, thin-bedded	3⅓
7.	Limestone, lithographic, shattered and unevenly bedded, brown, variegated	1
6.	Clay parting	⅙
5.	Limestone, compact	1¼
4.	Clay parting	⅙
3.	Limestone, buff to pink, lithographic	1⅓
2.	Limestone, gray, sub-crystalline	½
1.	Limestone, lithographic, dense, exposed	3

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*From notes supplied by Mr. C. L. Webster, Charles City, Iowa.

An average sample was selected from the above section and analyzed. The analysis is given herewith:

Calcium carbonate	92.85
Magnesium carbonate	5.31
Iron and alumina	0.80
Insoluble	1.60

A. O. ANDERSON, Analyst.

The magnesia percentage can undoubtedly be lowered by the elimination of number 9 in the above section which appears to be strongly dolomitic.

A large number of specimens have been selected from the various beds in the quarry and polished. Enough has been done to demonstrate thoroughly the superior quality of certain of the layers for lithographic purposes. It has also been demonstrated that the lithographic stone can be obtained in large slabs practically free from fractures, calcite balls, clay seams and other imperfections. Other beds take a good polish and are of a pleasing color. They can be quarried in blocks of almost any lateral dimensions and will undoubtedly find a ready market. The waste from the quarries would make an excellent grade of crushed stone. A large area is available with almost no overburden. A short line of railway has been surveyed and the company contemplates building in at an early date.

At Floyd, extensive quarrying has been done through a period of many years. A quarry just north of town along the main roadway shows the following beds:

		FEET.
8.	Drift and soil up to	4
7.	Limestone, brown, dolomitic	8
6.	Limestone, white to gray, compact, brittle	3
5.	Limestone, sub-crystalline, sugary, gray to brownish, apparently dolomitic	4
4.	Limestone, gray-white, blue above, compact, weathers concretionary	3
3.	Limestone, blue-gray, shaly above	4
2.	Limestone, brown, vesicular, dolomitic	1
1.	Limestone, compact, exposed	3

Many of the older buildings and nearly all foundations in the town attest the popularity of the stone for structural purposes.

Charles City is the chief quarry center in the county. Of the numerous quarries which have been opened and operated from time to time, a large quarry located in the southwestern part of town may be taken as a fair average. The beds developed are as follows:

CHARLES CITY SECTION.

		FEET.
4.	Soil, drift, and terrace materials, the latter constituting the larger portion of the overburden	4-8
3.	Limestone, ledge persistent	1-2
2.	Limestone, magnesian, light brown, vesicular and subcrystalline, less evenly bedded than number 1, concretionary in part	5-6
1.	Limestone, gray, weathers white, compact and brittle; evenly bedded, but beds undulating; comparatively free from flaws and remarkably uniform, exposed	8

The layers in number 1 are separated by thin clay partings which greatly facilitate quarrying operations. According to Mr. C. L. Webster, the stromatoporoid zones lie from fifteen to twenty feet below the base of the quarry. Number 1 in the above section is the chief quarry rock and has been used extensively in Charles City and the adjacent country. The M. E. Church and First National Bank buildings are among the more important structures constructed from local materials; the former bearing the date of 1854. Both are in good repair and the stone appears to possess excellent weathering qualities. The Charles City Marble Company owned and operated the quarry. This company also attempted to cut and polish the stromatoporoids for ornamental work but with indifferent success as a commercial venture, although some very handsome pieces were turned out.

South of Charles City, quarries have been opened at several points. On the south half of section 20, township 95 north, range XV west, east of the wagon road and north of a small creek, the following layers may be seen:

		FEET.
11.	Soil and drift, thin, up to	1
10.	Limestone, light colored, magnesian, shattered and fossiliferous	1
9.	Limestone, nodular, containing many stromatoporoids, badly broken, fossiliferous	4½

		FEET
8.	**Dolomite, brown**	**1⅙**
7.	**Limestone, lithographic, thinly bedded, where weathered, separating into thin plates**	**1⅙**
6.	**Limestone, compact, brown, becomes thinly bedded below in weathering**	**2**
5.	**Limestone, impure, earthy, forming a re-entrant in cliff face and breaking down, on weathering, to a yellow, clayey mixture**	**½**
4.	**Limestone, thinly bedded and light brown to bluish in color; laminæ separated by bands of weathered clayey residue**	**2½**
3.	**Talus slope**	**7**
2.	**Limestone, ledges similar to number 4, but heavier and firmer, with fewer clay partings and deeper brown in color**	**10**
1.	**Talus slope to creek bed**	**4**

Some quarrying was done formerly at this point. An abundance of material is easily available and under very light overburden.

In the southeastern portion of the county some quarrying has been done. The most important opening, the Allen quarry, two and three-fourths miles northwest of Nashua, is given herewith:

		FEET.
3.	Drift and soil of indefinite thickness.	
2.	Limestone, in thin beds, varying from one to five inches in thickness, some layers soft and granular, others hard and fine-grained	8
1.	Limestone, consisting of the following ledges from the bottom upward: eighteen inch, twelve inch, fourteen inch, eight inch and five six inch ledges respectively	7

The bottom ledge affords stone suitable for bridge work while several of the other ledges yield satisfactory building stone.

Some lime burning was done in Floyd county, as in the case of nearly every other limestone producing county in the state, but no lime has been produced during recent years.

FRANKLIN COUNTY.

The Owen beds of the Lime Creek stage outcrop at various points along the east side of the West Fork of the Cedar river in the northeast corner of Ross and throughout its course in West Fork township. In section 7, West Fork township, a small quarry has been opened, from which some rock has been removed. These beds furnish a supply of building material which has been utilized locally at many points. It is seldom, however, that the stone is sufficiently coherent to permit of any extended use for structural work.

The quarry opening just north of the road along the south side of section 7, West Fork township, affords the following section:

		FEET.
2.	Shale, yellow, magnesian, with chert nodules and, near the base, interbedded, sub-crystalline limestone, apparently dolomite. In places, definite bands of chert permeated with brachiopod impressions, *Spirifer whitneyi* most abundant	3½
1.	Dolomite, brown, thinly bedded, fossiliferous, partially crystalline; much shattered at top and badly rifted throughout, exposed	7

Only the lower bed can be used, and this on account of its coarsely granular and partially weathered condition, is not a durable material. It has been used to a limited extent for sidewalk flagging, and in walls, where it is fairly satisfactory.

HOWARD COUNTY.

Outside of two small areas marking the extensions of Ordovician beds which have been uncovered by the streams into Vernon Springs and across Albion township into Forest City township, the Devonian covers the entire county. The Devonian beds are accessible at numerous points and have been quarried principally at Vernon Springs and vicinity, Cresco, Lime Springs and vicinity, Chester, Elma and in section 33 in Saratoga township. The lowest beds developed may be viewed in the quarry located on the northeast corner of section 14 in Forest City township. The principal quarry rock consists of a massive, rough, rather soft, non-crystalline, vesicular dolomite. The quarry section is as follows:

		FEET.
5.	Limestone, dolomitic, ledges decayed and badly broken up; comparatively thinly bedded	8
4.	Dolomite, coarse, vesicular, full of fossil casts	5
3.	Dolomite, coarse, pitted like number 4	4½
2.	Limestone, dolomitic, light yellow	3
1.	Limestone, similar to 2 but softer and more granular; in four beds which in places appear to be completely blended into a single bed	4

Similar sections may be seen at other points in Forest City and Albion townships.

Beds somewhat higher in the series have been quarried at Vernon Springs and vicinity. The Salisbury quarry, located in the southwest quarter of the southwest quarter of section 34 in Vernon Springs township may be selected as a fair sample. The section is as follows:

SALISBURY SECTION, VERNON SPRINGS.

		FEET.
5.	Black soil mixed with broken rock	1
4.	Limestone, broken, angular fragments affording an illustration of how the stone yields to frost and weather	4
3.	Limestone in heavy courses of good building stone, soft, magnesian, yellow or brown in color, containing numerous spheroidal cavities lined with crystals of calcite, fossils rare and represented only by casts	8
2.	Limestone, softer, more argillaceous, in three or four layers, calcite lined cavities numerous	3
1.	Limestone, more solid and purer, in courses from one to three feet in thickness, fossil shells preserved	7

The most important quarry in the county is operated by John Hallman and is located in the northwestern part of the city of Cresco. The quarry pit shows the following beds:

		FEET.
4.	Drift and wash	1-4
3.	Limestone, in thin layers but evenly bedded and hard, magnesian	6-8
2.	Limestone, blue-gray, hard and tough, in beds ranging from 6 to 18 inches thick; works fairly well	7-8
1.	Limestone, dolomitic, base ledge in northwest corner of quarry; weathers brownish yellow, exposed	2

Numbers 1 and 2 contain considerable crystalline calcite in stringers and balls and the entire assemblage of beds is strongly magnesian. The quarry beds appear to be much disturbed in places, such disturbance being manifested by crushed layers and slickensided surfaces. The products of the quarry include some dimension stone, rubble and ordinary range stone. The principal beds are comparatively soft and work easily.

The quarries at Forest City and Chester work beds similar to those which have been developed at Vernon Springs.

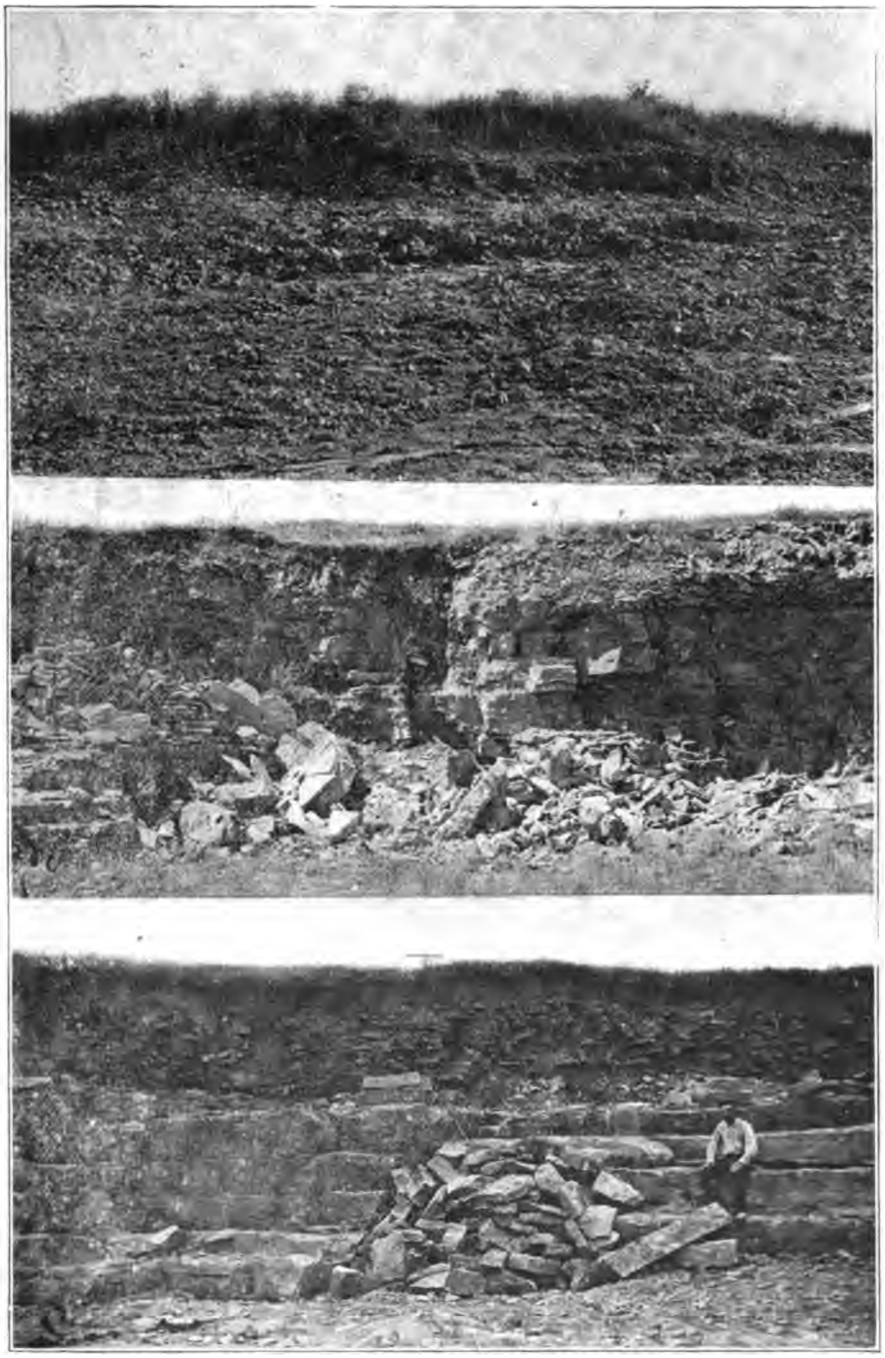

PLATE XLIX—a. City quarry about one and one-half miles north of Cresco. The product is a natural macadam.
b. Quarry northeast of Elma showing flaggy character of beds.
c Hallman quarry showing principal quarry beds. Cresco, Howard county, Iowa

At Elma several quarries have been opened and dolomitic limestones have been quarried, which, according to Professor Calvin, are below the beds occurring at Cresco. A quarry along the Chicago Great Western railway, north of Elma, displays the following beds:

		FEET.
4.	Soil and drift	0-3
3.	Limestone, much weathered, bedding planes almost obliterated, somewhat concretionary in appearance	3-5
2.	Limestone, magnesian, stained yellowish brown where long exposed; breaks up into thin layers although apparently in heavy beds	3-5
1.	Dolomite, brown, sub-crystalline and cavernous, calcitic, in heavy beds	4

Small quarries have been opened and operated from time to time at other points but none are worthy of special mention.

LIME.

The Devonian limestones are prevailingly magnesian to dolomitic as developed in Howard county and are fairly free from impurities. They would undoubtedly yield an acceptable grade of lime should they be used for that purpose. In fact a good grade of lime was manufactured from the dolomitic limestone at Vernon Springs before the railways brought in limes from other counties where it could be produced more cheaply.

JOHNSON COUNTY.

Rocks of Devonian age immediately underlie the drift over more than half of the county. Numerous exposures occur along the Iowa river and its more important tributaries. The beds represented are referred to three well known sub-stages of the Devonian. The lowest belong to the brecciated stage of the Wapsipinicon and are exposed at only a few points in the northeastern portion of the county. These beds have been quarried in a small way at Solon and near Elmira. The layers are much shattered as a rule, and the blocks obtainable are rough and poorly shaped for structural purposes. The stone supplied from these beds is of local interest only.

The Cedar Valley stage is well developed and affords the largest number of outcrops. Quarries have been opened and operated at numerous points. A few, only, are given for reference. The majority of the openings are without transportation facilities but show the latent wealth of the county in structural materials. A quarry opened south of the old Terrill mill in Iowa City shows the following succession of beds:

TERRILL MILL SECTION.

		FEET.
8.	Hard, ferruginous, reddish brown sandstone of Des Moines stage, Upper Carboniferous	6
7.	Limestone, whitish gray, fine-grained	8
6.	Idiostroma beds, containing as usual many massive stromatoporoids and some coralla of Acervularia	15
5.	Limestone, heavy, tough ledge	4
4.	Limestone, bluish gray, weathering yellow, containing large coarse-ribbed Atrypas and the small branched, small celled Cladopora found at same horizon in Eicher's quarry	8
3.	Limestone, bluish gray, in two ledges, first ledge containing many crinoid stems	4
2.	Coral reef	2
1.	Limestone, bluish, with great numbers of broken, crushed, detached valves of *Spirifer parryanus* and the robust, large celled Cladopora (*C. iowensis* Owen sp.) described as *Striatopora rugosa* by Hall	2

The coral reef bed is very persistent and constant. The beds above the reef vary considerably. In places they are hard bluish gray limestone, in other places, partly on account of weathering, they are yellow limestone and in still other localities they present the appearance of yellow calcareous shales. At the old railway quarry on the west bank of the river north of Coralville, the following beds may be seen beneath the overlying loess and drift:

CORALVILLE SECTION.

		FEET.
5.	Limestone, white	12
4.	Limestone, stratum crowded with casts of *Straparollus cyclostomus* Hall	1½
3.	Limestone weathering into thin fragments, containing some specimens of Idiostroma and colonies of a cylindrical Favosites	4
2.	Limestone, gray, crowded with Idiostroma and other stromatoporoids. This with No. 3 represents the Idiostroma beds of preceding sections	8
1.	Limestone, hard, blue, containing some large coralla of Acervularia	4

These beds were formerly worked by the Railroad Company for crushed stone. A switch was extended to the quarry and a large amount of railway ballast produced. One of the most extensive quarry sections may be observed on the east bank of the Iowa river in the northwest quarter of section 27, Newport township. The following beds below the loess and drift are exposed:

		FEET.
9.	Limestone, brown, with crinoid stems, a Cladopora related to the form described by Hall as *Striatopora rugosa*, but having the branches and polyp tubes very much smaller, and a large coarsely ribbed variety of *Atrypa reticularis*...	4
8.	Limestone, drab, granular, no fossils	8
7.	Coral reef composed chiefly of corolla of *Acervularia davidsoni* E. & H., but containing many coralla of Favosites and Ptychophyllum	2
6.	Limestone, moderately hard bed with crinoid stems, *Spirifer parryanus*, *Atrypa reticularis*, Favosites, Cyathophyllum, Cystiphyllum, etc......................................	1½
5.	Limestone, shaly, with many small crinoid stems, *Chonetes scitula* Hall, *Spirifer parryanus* Hall, *Tentaculites hoyti* White, and *Monticulipora monticola* White................	1½
4.	Limestone, hard ledge with many small crinoid stems, Cladopora, Ptychophyllum and some large coralla of Acervularia	2
3.	Limestone, yellow shaly bed with Atrypa, Orthis, etc........	2
2.	Limestone, yellow and gray, shaly, without fossils..........	13
1.	Limestone, moderately hard, intersected by a number of oblique joints, light colored, laminated, with many stem segments and some perfect calyces of Megistocrinus and other species characteristic of the Megistocrinus fauna. Megistocrinus beds......................................	15

The quarry north of the iron bridge in section 25, Jefferson township, shows some modifications of the succession of strata occurring farther down the river. The section is as follows:

		FEET.
10.	Loess	2-10
9.	Pebbly drift, Kansan......................................	3
8.	Limestone, decayed, with bowlders of disintegration embedded in highly oxidized dark reddish brown residual clay...	3
7.	Limestone, light colored, evenly bedded, fine-grained........	10
6.	Coral breccia, composed of coralla of Acervularia, small cylindrical Favosites, a peculiar Diphyphyllum, a very elongated Cyathophyllum, Idiostroma and massive stromatoporoids	5-8
5.	Reef of closely crowded masses of Acervularia..............	2
4.	Limestone, regular heavy layers of fairly good quarry stone, containing coralla of Acervularia and Favosites sparsely distributed	5

		FEET.
3.	Limestone, blue, in layers from 6 inches to 2 feet thick, composed of fragments of crinoids and broken shells of brachiopods	7
2.	Shale and shaly limestone	1½
1.	Limestone, heavy, blue, with concretions of pyrites	2

Nearly all of the beds given in the above sections supply materials suitable for foundations and rough masonry and have been so used to some extent at one time or another.

The uppermost member of the Devonian as developed in the county has been named the State Quarry Limestone by Professor Calvin, and is not known to occur in any other county in the state. The formation is assigned to the Upper Devonian and attains a thickness of forty feet, and while it has been recognized at a number of points in the county, it is typically developed at the State Quarries, or North Bend quarries, in sections 5 and 8 of Penn township. On fresh fracture the State Quarry rock is light gray in color. In texture it varies somewhat in different beds but near the middle of the formation it is composed of coarse, imperfectly comminuted fragments of brachiopod shells cemented together, the spaces being filled with interstitial calcite. The shells, or fragments of shells, making up the limestone are not embedded in a matrix but are simply piled on each other and cemented.

Near the middle of the formation the rock consists of thick ledges which, some years ago, were worked extensively. From these beds came the large limestone blocks used in the foundation of the new state capitol. Although the ledges show no definite lamination, and split as readily in one direction as another, the weathered surfaces on opposite sides of the numerous joints often show obscure signs of oblique bedding. The chief quarry ledge is five feet thick and rests on a four foot ledge which is not used. The next usable ledge in ascending order is also five feet in thickness and is separated from the first by two or three feet of talus. The fourth ledge is four feet thick and is very fine-grained. Above this the beds range from six inches to two feet in thickness; these beds are made up wholly of crinoidal remains. Below the first heavy ledge mentioned the rock is thinly bedded.

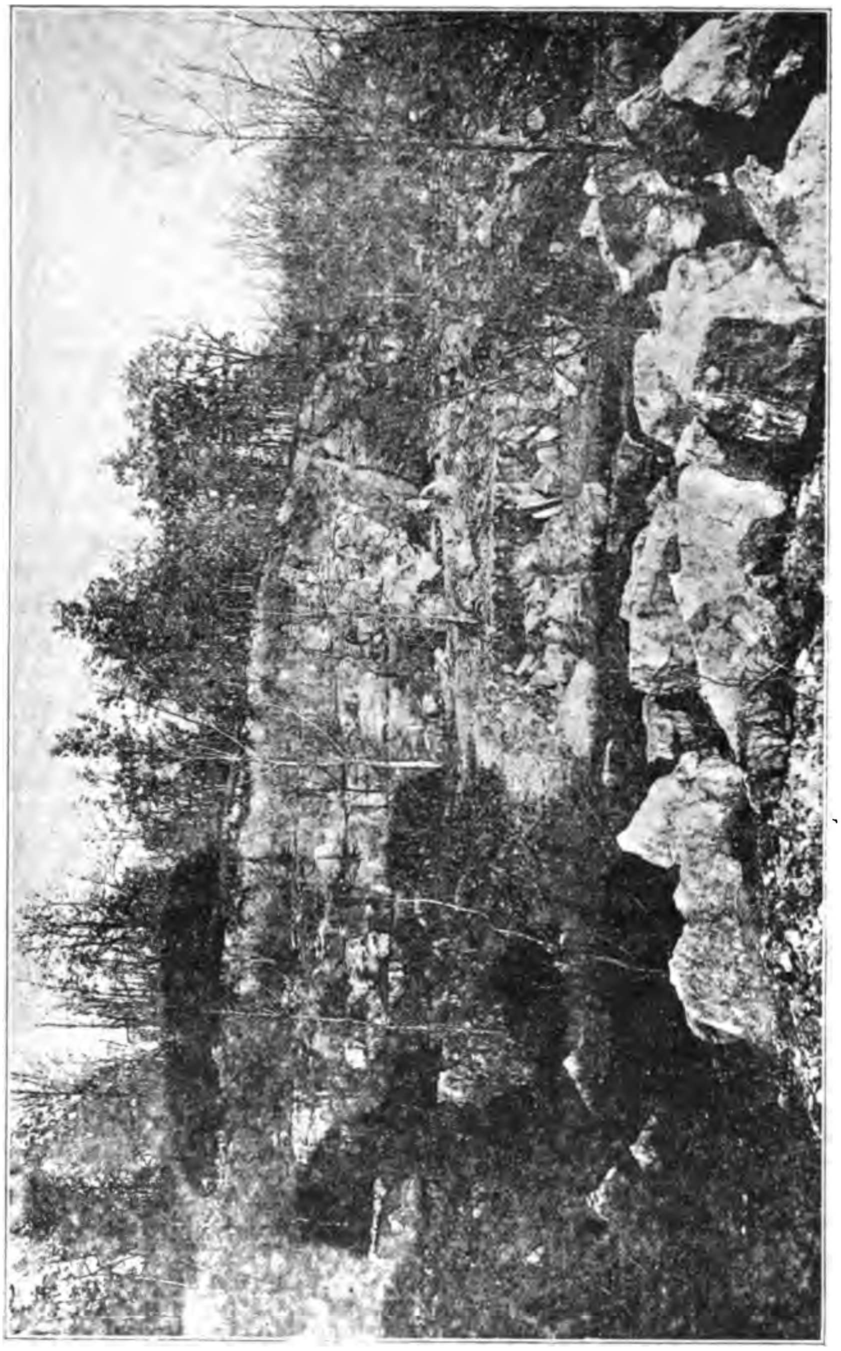

PLATE L.—State quarry beds, State Quarry, Johnson county, Iowa

While there is still a large amount of excellent material for bridge work and massive masonry available the lack of proper transportation facilities has caused the temporary abandonment of the quarry.

LIME.

The LeClaire beds afford excellent material for strong, slow slaking and slow setting lime, but they have not been used for that purpose in the county. Lime has been burnt from the more highly calcareous beds of the Devonian but not being able to compete with the better limes from other counties, the industry has been abandoned.

LINN COUNTY.

The Devonian limestones cover about two-thirds of the superficial area of the county and are quite generally exposed along the principal streamways, but notwithstanding these facts, comparatively little dimension stone is derived from any of the beds. The Anamosa beds of the Niagara practically have a monopoly of the commercial building stone trade in this part of the state. All of the members of the Devonian represented in the county furnish some stone suitable for structural purposes, especially crushed stone.

The Coggan beds of Norton, formerly referred to the Niagara but at present included in the Devonian, are dolomitic, heavy-bedded, destitute of lamination and often porous and highly vesicular. When sufficiently compact, the stone is well adapted for bridge work and other heavy masonry. A quarry near the railway station at Coggan gives a fair idea of the beds and is as follows:

COGGAN SECTION.

		FEET.
4.	Soil, loess and drift of variable thickness.	
3.	Limestone, gray, hard, compact, sub-crystalline, magnesian; layers from one to four inches thick, weathering into block-chipstone	2
2.	Limestone, massive, pale buff, magnesian, moderately hard, granular, sub-crystalline; porous or vesicular, with a few irregular cavities about an inch in diameter; in layers eighteen to twenty-four inches thick. In places the rock	

		FEET.
	weathers into chipstone, and is a brownish buff, semi-earthy, semi-crystalline limestone. (Exposed to quarry floor)	8
1.	Slope to water in river, elsewhere seen to be occupied by massive limestone as above	6

The beds exposed here are quite variable texturally and in color. They vary from a compact, subcrystalline limestone to a highly vesicular to earthy material almost pumaceous in character. The full thickness of the Coggan beds is displayed a short distance above the dam at Central City. The sequence is as follows:

CENTRAL CITY SECTION.

		FEET.
6.	Soil, loess and drift, variable thickness.	
5.	Limestone, even-bedded, non-magnesian above, becoming more and more magnesian below, and so graduating by thin layers into the beds below that the line between them is somewhat arbitrarily drawn (Otis Beds)	12½
4.	Limestone, magnesian, light buff, compact, granular	⅚
3.	Limestone as above, darker, also non-fossiliferous excepting some minute vermicular cavities; in three layers	1
2.	Limestone, massive, buff, magnesian; with moulds and casts of fossils, as at Coggan; porous and vesicular; upper layer cherty, with dark nodules forming in places a continuous band. The layers from above downward are respectively one foot, five feet and ten inches, eleven inches, and four feet ten inches in thickness	$12\frac{7}{12}$
1.	Unexposed to river	10

Numbers 2, 3 and 4 of the above belong to the Coggan beds. These beds maintain their level to a fine exposure on the left bank of the river, two miles northwest of Central City, at Granger's old quarry.

The Otis beds of Norton have been exploited more extensively for crushed stone than any other. Several large crusher plants are located in Cedar Rapids and vicinity and furnish stone for street and road work, concrete and railway ballast. The principal plants are located east and south of town on either side of the Cedar river. One of the largest plants running at the present time is operated by J. J. Snouffer, Jr., and is located along the Chicago, Rock Island and Pacific railway in the south part of town. The beds exposed are approximately as follows:

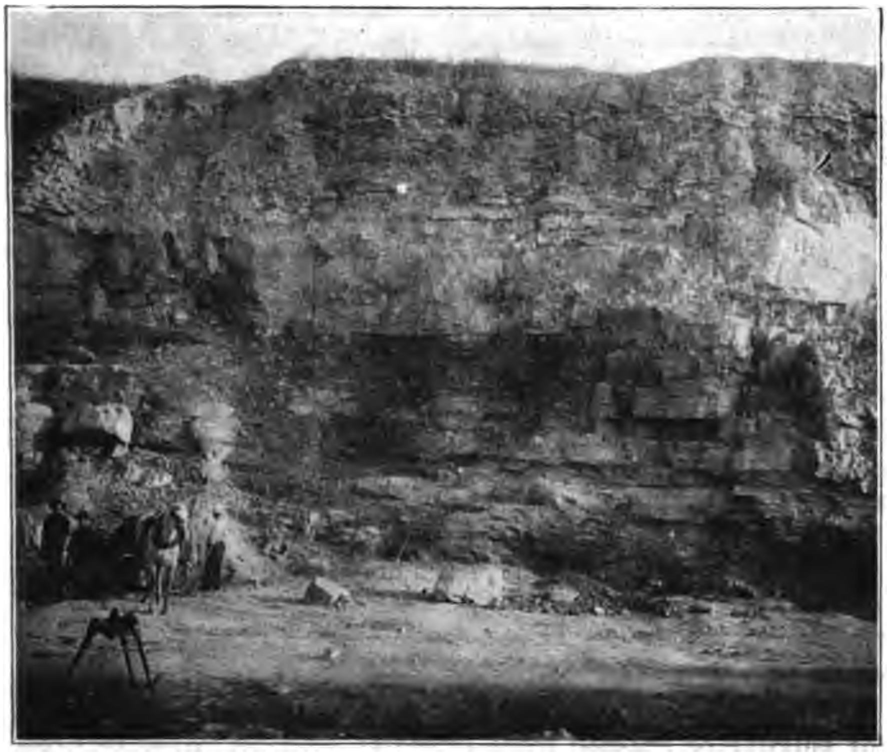

FIG. 25—Snouffer quarry, Cedar Rapids, Linn county, Iowa.

		FEET.
12.	Loess stripping	12-20
11.	Thin bedded, shelly, weathered limestone, for the most part worthless; portions of lower ledges usable in crusher	11-12
10.	Light brown, saccharoidal limestone, heavy ledge, containing cavities and masses of crystalline calcite, in places, contains numerous fragments of soft yellow limestone, prominent in face of quarry	4
9.	Similar to No. 10 but more distinctly laminated and separates readily along bedding planes	2
8.	Laminated, soft magnesian limestone, sandy to the feel, porous; thin bedded and breaks well both horizontally and vertically, contains occasional small calcite cavities	4
7.	Limestone, dense brown, non-crystalline ledge	2½
6.	Ledge, dark brown in color, including in places thin layers of black, carbonaceous clay	1½
5.	Limestone ledge, light drab in color, has suffered shattering, cut by thin, irregular veins of crystalline calcite; close texture and conchoidal fracture	1¾

		FEET.
4.	Dark brown limestone, in large part coarsely crystalline; hard and breaks very irregularly	1⅙
3.	Hard, close textured limestone, has apparently been shattered and recemented by numerous veinlets of calcite; displays fine wavy laminations	2⅙
2.	Shale, black, carbonaceous and contains fragments of limestone, in places soft and plastic	⅙-¼
1.	Sugary brown dolomite in layers from two to six inches, alternating laminæ of varying shades; the darker weathering to a residue of dusty sand; breaks irregularly except along planes of stratification	5

This quarry is located in close proximity to the Chicago, Rock Island and Pacific tracks. At present the total output is crushed stone. The crusher is located on the railroad and the stone hauled by horse and cart up a low incline. Four grades of crushed product are put on the market, viz.: No. 1 ranging in size from 1 to 2½ inches; No. 2 from ½ to 1 inch, No. 3, ¼ to ¾, and No. 4, below ¼ inch in diameter and termed "rock dust."

The upper beds of the Wapsipinicon are quite generally brecciated and as a consequence have been but little quarried. These beds have been developed in a small way at Marion, and in the vicinity of Cedar Rapids and Flemingville.

The Cedar Valley beds are often too shaly to be of much use for building or crushed stone purposes. As developed in Linn county, they break up readily under the action of frost and are not evenly bedded. The best quarries are in the vicinity of Center Point, Toddville and Troy Mills. At best the stone produced is not to be recommended for important structures.

MITCHELL COUNTY.

The Cedar Valley limestone of the Devonian forms the country rock over the entire county. Excellent sections may be seen along the principal streams, especially along the Cedar river west of Osage. Practically the entire series of beds known to occur in the county appear in a single section aggregating about eighty-five to ninety feet. According to Professor Calvin in his admirable discussion of the Geology of Mitchell county the details of one of these standard sections are as follows:

The Chandler Cliff Section, located on the east side of the river on the southeast quarter of the southeast quarter of section 21, directly west of Osage:

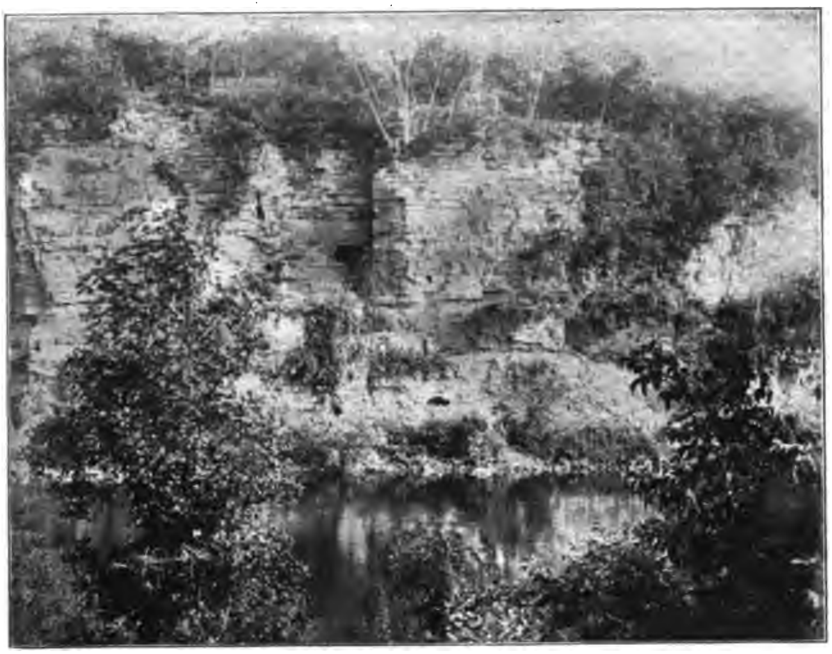

FIG. 26—Cliff below the wagon bridge in the northeast quarter of section 28, Osage township. There are folded and brecciated beds at the base of the cliff; the lithographic limestone appears at the top.

		FEET.
26.	Residual clay in which thin, weathered slabs and flakes of limestone are embedded, part of mantle of waste	4
25.	Limestone, coarse-grained, rough, weathered, magnesian	½
24.	Limestone, firm, fine-grained, lithographic ledge, somewhat concretionary and containing imperfectly preserved stromatoporoids	1
23.	Limestone, partly decayed and partly shaly layer	1
22.	Limestone, fine, light colored, lithographic bed. The bed as usual shows two divisions which are separated by a peculiar suture-like joint due to the interlocking of small prominences from the apposed surfaces. This interlocking joint is seen in all the exposures of this vicinity. The interlocking denticles show stylolitic structure	2
21.	Shaly parting	$\frac{1}{12}$
20.	Limestone, lithographic, in three parts; upper part as usual very fine-grained and homogeneous	2½
19.	Shaly parting	⅙
18.	Limestone, lithographic, fine-grained	1
17.	Limestone, coarse, dolomitic	1
16.	Limestone, fine-grained, laminated	1

		FEET.
15.	Dolomite, coarse, granular, in beds ranging from six inches to a foot in thickness	4
14.	Shaly parting	$\frac{1}{4}$
13.	Limestone with lithographic nodules embedded in granular matrix	$1\frac{1}{6}$
12.	Limestone, heavy layer which is dolomitic below and partly lithographic above. The lithographic portion is joined to the coarser dolomite by a wavy and irregular line	$1\frac{1}{6}$
11.	Shaly band, variable in thickness, averaging about	$\frac{1}{4}$
10.	Dolomite, heavy layer, sub-crystalline	$1\frac{1}{4}$
9.	Shaly parting	$\frac{1}{6}$
8.	Limestone, thick layer, coarse and granular at the base, upper six inches partly lithographic	$1\frac{1}{2}$
7.	Limestone, hard, light gray, lithographic stone	$1\frac{1}{12}$
6.	Limestone, shaly, decayed	1
5.	Limestone, light gray, crystalline, good building stone	$1\frac{1}{6}$
4.	Dolomite, evenly bedded, yellowish, good quality, quarried for building stone at many points in the county, layers ranging up to a foot or more in thickness, no fossils	9
3.	Dolomite, irregularly and indefinitely bedded, much checked and cut by joints, carries numerous casts of *Athyris vittata* and other species characteristic of the same horizon. This member will be referred to hereafter as the Athyris zone	12
2.	Limestone, two heavy, irregular, non-laminated, dolomitic beds, containing many shapeless cavities lined with calcite	5
1.	Limestone, magnesian, partly dolomitic, in regular layers	15

For convenience a generalized section may be composed from the above section and one or two others in the immediate neighborhood. The following is believed to closely approximate the truth:

GENERALIZED DEVONIAN SECTION.

		FEET.
8.	Magnesian limestone above the lithographic zone, represented usually by weathered chips	6
7.	Lithographic zone	9
6.	Assemblage of variable beds between the lithographic zone and the evenly bedded quarry stone	15
5.	Quarry stone, No. 4 of the Chandler cliff section	10
4.	Athyris bed	12
3.	Coarse, vesicular bed with calcite-lined cavities	5
2.	Regular bedded dolomite at base of Chandler section	15
1.	Folded and brecciated zone	15

Number 1 in the general section may be seen one-fourth mile below the electric power plant just below the wagon bridge directly west of Osage. The upper portion of the section closely resembles Chandler's Cliff.

The principal streams in the county are strike streams and the general slope is parallel with the dip south and west. The beds which are quarried at St. Ansgar are essentially the same as those quarried at Orchard, and those being developed in the vicinity of McIntire find their counterparts in the quarries along Rock creek.

In the vicinity of Osage quarrying operations are limited almost wholly to the lithographic beds. Near Mitchell and St. Ansgar, and along the Little Cedar from Stacyville to Brownville, the regularly bedded dolomites, corresponding to number 4 in the Chandler section, are worked. At McIntire and along Rock creek the lithographic zone is the one mainly utilized. At Otranto the Athyris bed is worked and it would appear that number 1 of the Chandler section ought to be within working distance of the surface. In order that the details may be better understood and the latent resources of the county more fully appreciated, a detailed quarry section from each of the more

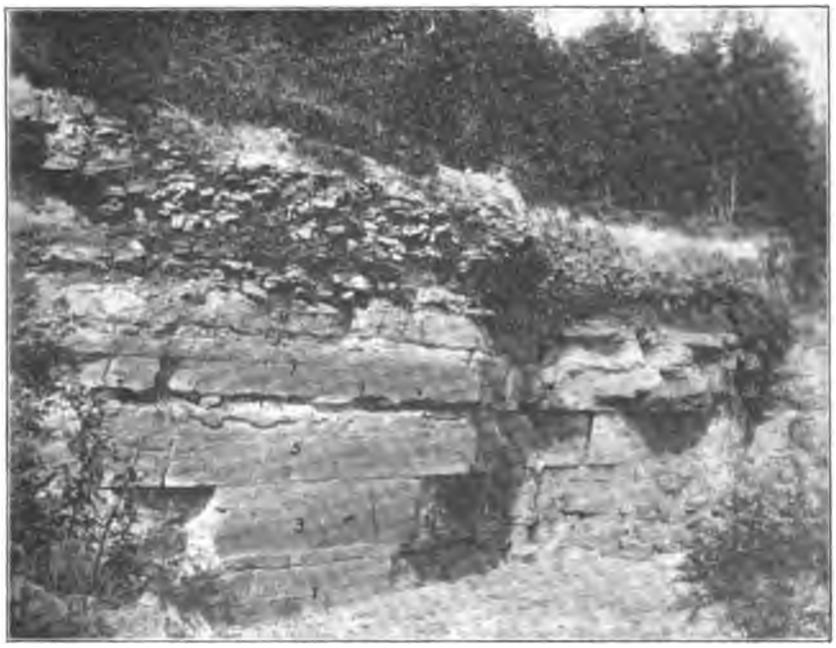

FIG. 27—The Lewis lime quarry, in the southeast quarter of section 27, Osage township, one and one-half miles southwest of Osage.

important districts is given below. A considerable number of quarries have been opened along Sugar creek southwest of Osage. One of the most important of these is known as the Lewis lime quarry. The section is as follows:

LEWIS LIME QUARRY.

		FEET.
10.	Dark brown residual clays with some granular, calcareous, residual material resembling fine sand, and many weathered chips of limestone	4
9.	Limestone, firm, whitish, fine-grained ledge of concretionary lithographic stone containing a number of obscure stromatoporoids	⅚
8.	Limestone, shaly, fossiliferous, fossils mostly in the form of comminuted brachiopod shells	½
7.	Limestone, hard, fine-grained, lithographic, with lamination planes well defined in some places, less perfectly defined in others, and with a tendency to split up into individual layers of varying degrees of thickness	1⅙
6.	Shale, marly	½
5.	Limestone, heavy ledge of fine-grained lithographic stone dividing into two parts, the upper ten, the lower seventeen inches in thickness. The lower five inches is very fine and homogeneous in texture and tends in places to separate as a distinct layer	2¼
4.	Thin shaly parting	1/12
3.	Limestone, ledge of fine-textured lithographic stone in three parts, eight, seventeen and one-half, and three and one-half inches respectively	2⅓
2.	Shaly parting	1/12
1.	Limestone, coarser and less perfect lithographic stone, in two parts eleven and nine inches thick	1⅔

Beds 3, 5, 7 and 9 are fine-grained and light colored, break with conchoidal fracture, and would all be classed as lithographic limestone. It is the upper eight inches of No. 3 and the lower five or six inches of No. 5 that are fine enough and homogeneous enough to give promise of possessing commercial value as serviceable lithographic stone. All the beds are checked and jointed on an extensive scale, and this renders it difficult to obtain blocks of usable size for lithographic purposes.

The lithographic beds are quarried at an opening on the land of Dr. W. H. Gable in the northwest quarter of the southeast quarter of section 27 about half a mile northwest of the Lewis quarry. The lithographic beds here, as elsewhere, are remarkably durable as evidenced along natural fissures. Detached blocks which bear evidence of long exposure, ring when struck with the hammer and show slight indication of surface softening and disintegration. An average sample was taken from the Gable quarry and analyzed. The results were as follows:

Insoluble	2.21
Iron and alumina	3.82
Calcium carbonate	90.17
Magnesium carbonate	1.03
Moisture and organic matter	2.63
	99.86

A. O. ANDERSON, Analyst.

The sections exposed at St. Ansgar and Mitchell show no new facies. The dolomitic beds are worked the most though the lithographic beds are available at the latter place. At Otranto only the lower beds exposed in the Chandler section are known, while along the Little Cedar the middle to lower beds are available.

Near McIntire the following section exposed near the mill southeast of the town may be taken as a fair average. The beds exposed are as follows:

		FEET.
5.	Loess and soil	6
4.	Limestone, decayed, magnesian, granular	2
3.	Limestone, laminated, lithographic stone	3
2.	Limestone, solid, granular and fossiliferous	1½
1.	Limestone, thin-bedded, partly lithographic stone, variable	2

In the bed of the small creek between the quarry and the mill, there are firm dolomitic beds below the level of the above section. The entire assemblage of beds in this part of the county are supposed to be the equivalents of those exposed near the top at Osage and Orchard.

Notwithstanding the abundance of excellent structural materials available none of the quarries are of more than local importance.

LIME.

Two small kilns still exist southwest of Osage along Sugar creek. Lime is not regularly produced, however, as the kilns have been idle for several years. The lithographic beds were utilized and a good grade of white lime was produced.

MUSCATINE COUNTY.

While stratified rocks of Devonian age are believed to form the country rock immediately under the glacial debris over the larger portion of the county, exposures are practically limited to Moscow, Sweetland, and Montpelier townships. Unimportant outcrops are also known to occur in the city of Muscatine. The lowest limestone beds exposed are prevailingly brecciated in character, and carry a high percentage of calcium carbonate, being almost pure limestones, and are non-fossiliferous. The upper limestone beds are rich in organic remains and oftentimes are magnesian to dolomitic in character. Quarrying operations have been carried on on only a small scale, save near the Mississippi river where considerable material has been used for Mississippi river improvement work by the Federal Government. A composite section compiled from the outcrops in the vicinity of Moscow is about as follows:

		FEET.
6.	Drift and surface detritus of variable thickness.	
5.	Limestone, hard, gray, in rather irregular ledges, fossiliferous and somewhat brecciated; mixed with the rock below......	5
4.	Limestone, softer than above, mostly concealed, with frequent crinoid stems above; blue and fine-grained ledges farther down, slightly crushed or brecciated in the lowest part; fossiliferous	29
3.	Limestone, strong, gray, in moderately heavy and regular ledges, slightly broken or brecciated in a few places, fossiliferous	8
2.	Limestone, coarsely brecciated, emitting a faint, bituminous odor under the hammer	4
1.	Limestone, white, evenly bedded, in thin layers.............	4

Numbers 1 and 2 are exposed only along Sugar creek northeast of Moscow, while the upper members appear west of the town. Quarries have been operated from time to time at several points.

Numerous outcrops of Devonian limestone somewhat higher in the series than those about Moscow may be viewed along the Mississippi river and its immediate tributaries from the eastern border of the county to the city of Muscatine. The best developed and least obscured sections occur in the vicinity of Montpelier and along Pine creek.

Along Sulphur branch, a creek which enters the Mississippi about one mile east of Montpelier, the following beds appear:

		FEET.
7.	Drift and soil, of variable thickness.	
6.	Limestone, weathered ledges, with scattered casts of cup corals	2½
5.	Limestone, black, carbonaceous, with Stromatopora..........	½
4.	Limestone, bluish, dolomitic, thick-bedded, with fossil casts..	9
3.	Shale, soft, fossiliferous....................................	1
2.	Limestone, in thin hard ledges, with small, kidney-shaped or cake-like Stromatopora..................................	2
1.	Limestone, dolomitic, bluish, finely granular; fossiliferous, exposed	4

Nearer town number 1 in the above section is seen to rest on a bluish clay of unknown thickness. The upper beds have been quarried, number 4 having been quarried most extensively. These ledges exhibit some of the characteristics of a "freestone," breaking almost as readily in one direction as in another. The bedding planes are even and well marked. The lowermost ledge of number 4 is two feet in thickness. When subjected to weathering influences, the beds tend to become clayey.

Near the center of section 21 in Montpelier township, large quantities of material have been obtained for the construction of wing-dams farther down the river. The section exposed at this point and near vicinity is as follows:

		FEET.
8.	Drift and soil, variable thickness.	
7.	Limestone, hard, brown, weathered, apparently somewhat brecciated and containing fragments of Stromatopora......	4
6.	Concealed..	5+
5.	Limestone, weathered, apparently brecciated, with a large Stromatopora above a dark carbonaceous layer near the base, carrying casts of an Amplexus.........................	4
4.	Limestone, dolomitic, almost white, bluish, finely granular and evenly bedded; in heavy ledges, the lowermost nearly four feet thick, rapidly turning darker blue and yellowish on exposure; oblique, curving fracture in some places, fossiliferous	8
3.	Limestone, hard, in thin layers and rough, but straight layers above; fossiliferous......................................	2½
2.	Concealed..	3
1.	Limestone, dolomitic, bluish or gray, with Cystodictya	2

Number 1 disappears under the creek and also under the water in the river.

Sections along the lower course of Pine creek are practically the same as the one just given. Higher up the stream beds lower in the series appear. Possibly the most extensive succession may be studied in an old quarry in the south bank of a small tributary of Pine creek in the northeast quarter of the southeast quarter of section 4 in Montpelier township.

CARPENTER QUARRY SECTION.

		FEET.
8.	Drift and soil, of variable thickness.	
7.	Limestone, much decayed and appears to be a yellow clayey material; fossiliferous	7
6.	Limestone, hard, solid ledges, a foot in thickness, in places highly fossiliferous	3
5.	Limestone, fine-grained ledge, cut by a net-work of vertical plates made up of material like that in the ledge above	⅔
4.	Marl, earthy	⅙
3.	Limestone, fine-grained, gray, thin-bedded above, thicker bedded and dolomitic below, Gomphoceras and a reniform Stromatopora in upper part, Cystodictya below	2
2.	Concealed	5
1.	Limestone, gray, in somewhat irregular ledges, fossiliferous, exposed	3

Numbers 3 to 6 are the beds developed in the above quarry and in the immediate vicinity.

From the mouth of Pine creek, crops of Devonian limestone continue to the city of Muscatine, but none are of sufficient importance commercially to merit individual mention.

The upper Devonian beds exposed in the county constitute the Sweetland Creek beds of Udden. They are prevailingly argillaceous in character, although they contain certain hard magnesian to dolomitic layers below. The well indurated beds are neither sufficient in quantity nor sufficiently accessible to be worthy of consideration. Certain of the shale members are highly bituminous while others contain a considerable percentage of lime phosphate.

SCOTT COUNTY.

Devonian limestones have been quarried extensively from Pleasant Valley to Buffalo along the Mississippi river. The most extensive quarries are located at Bettendorf east of Davenport and at Linwood near Buffalo. Several companies are operating near Bettendorf, crushed stone being the chief product.

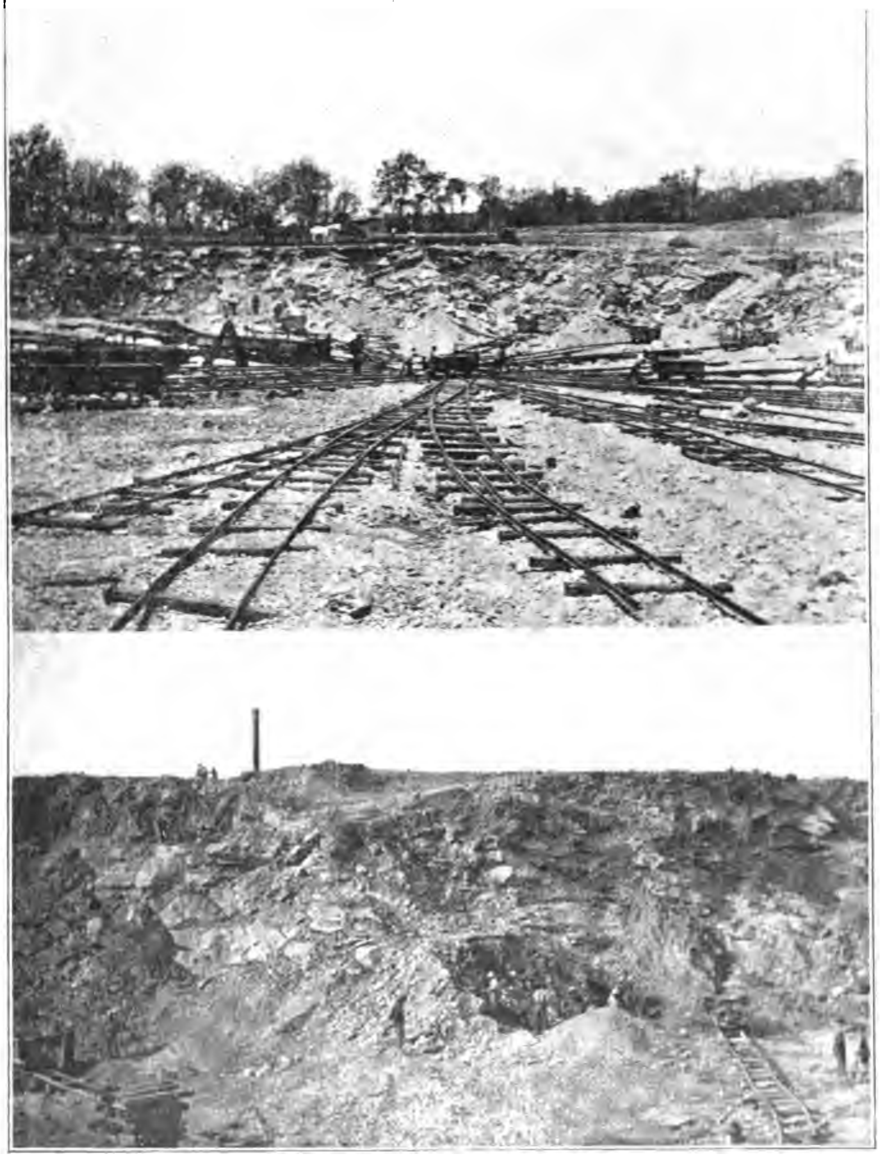

PLATE LI.—Clark quarry, near Buffalo, Scott county; upper view showing trackage arrangements leading to incline, lower view showing irregular beds and large amount of shaly talus.

The Grommoll quarry is located east of Bettendorf and south of the electric railway tracks. The pit section aggregates ten to twelve feet. The upper six to eight feet is composed of a thinly bedded, brittle, white limestone while the lower four feet developed comprises heavier beds of gray to buff limestone. The upper beds in their entirety along with the spalls from the lower beds, are put through the crusher, while the lower beds supply some rubble stone. The stone is hoisted by derricks and dropped directly into a Brennan crusher (Blake type, jaws in three parts working separately). The crushed product is elevated to a cylindrical screen and sized, the screened product falling directly into storage bins from which it is loaded into cars. The output is used to a large extent locally.

The LeClaire Stone Company has a plant just west of the Grommoll quarry. The pit has been opened to a depth of about twenty feet. The section is the same as the preceding, save that the lower beds are more important and furnish a good grade of rubble and some range stone. The beds are gray-blue in color and range from eight to sixteen inches in thickness. The bedding planes are not very apparent. The plant is equipped with steam drills, steam hoists, and two Gates crushers. Both plants produce a superior grade of crushed stone, and practically no stripping is required at either plant.

At Linwood, east of Buffalo and north of the railroad tracks, the Linwood Quarry Company installed a crusher plant a few years ago and is producing crushed stone only. The pit shows much shattered beds of white to shaly limestone. In places the color of the stone is somewhat variegated. The plant is equipped with a Blake crusher and a number 5 Austin crusher, and the necessary trackage and derricks. A small amount of rubble is produced.

A new crusher plant has been opened recently just west of Buffalo on the Clark farm. The stone developed is similar to that at Linwood but appears to be less shaly. The plant is one of the largest in the state, having a capacity of 100 yards per hour, and is equipped with a number 7½ and a number 5 Austin crusher. The plant is well housed and is supplied with a full complement of up-to-date machinery. The stone is loosened by drilling and heavy charges of dynamite. Compressed air is used in drilling. The stone is loaded into cars having a capacity of two yards and drawn by a rope up an incline to the crusher. Most of the output is taken by the Chicago, Rock Island and Pacific Railway for ballast.

The Wapsipinicon stage of the Devonian has produced and is capable of producing some very good dimension stone and dressed stone, especially rock-faced ashlar. Trinity church, Davenport, is an example of the stone obtained from the upper Davenport beds, while the cathedral of the Protestant Episcopal Church was built from stone obtained from the Lower Davenport beds.

The Middle Devonian beds as represented by the Cedar Valley limestone, are for the most part too argillaceous to afford building stone of good quality. Several of the lower layers furnish stone of fair quality and several quarries have been opened to develop them, the most important of which are located near Buffalo. One of the most extensive quarries is located on the southwest quarter of section 13, Buffalo township. The beds worked are as follows:

		FEET.
2.	Limestone, hard, gray, sub-crystalline, fossiliferous, in horizontal layers ranging from four to nine inches in thickness.	7
1.	Limestone, argillaceous, blue weathering buff, upper nine feet highly encrinal, main joints run north, 35 degrees east and do not continue upward into number 2..............	14

The other quarries of the township present very similar sections. Most of the stone quarried was used for river improvement work by the government. Some has been used for road work and rough masonry.

LIME.

The LeClaire beds of the Silurian afford an almost inexhaustible supply of material suitable for lime burning and are extensively developed across the river from LeClaire at Port Byron. At the present time this most excellent limestone is not being used in the county. Some lime burning has been done near Dixon and Gilbert, but white Devonian limestones have been used. The annual output is small.

WORTH COUNTY.

Limestones of the Mason City sub-stage of the Cedar Valley stage outcrop in the banks of both the Shell Rock river and Lime creek and their chief tributaries. The strata are similar in every way to their equivalents in the Mason City sections in Cerro Gordo county.

On the Shell Rock a maximum thickness of twenty feet of the limestone beds may be observed at the railroad bridge in section 1 of Lincoln township.

The following section at Foster's mill in the northeast corner of section 30, Union township, is typical for the Cedar Valley beds:

		FEET.
4.	Weathered limestone, crystalline, and containing numerous calcite cavities	10
3.	Compact, light colored, dolomitic limestone, heavy bedded	4
2.	Very close textured limestone, lithographic in appearance, hard and breaking with conchoidal fracture. Has a very characteristic ring when struck with the hammer	3
1.	Argillaceous, bluish dolomite layer, exposed to water below dam	1

No. 4 is the Stromatopora zone which characterizes this stage at nearly every exposure. It is the equivalent of the beds that are to be employed for the manufacture of Portland cement at the Mason City plant, in the adjoining county to the south.

Near the south edge of section 12, Lincoln township, is a small quarry from which crushed stone has been taken for road material. The middle layer of the Foster mill section is the one used.

Beginning in the northwest quarter of section 1, Lincoln township, is a continuous outcrop for about one-third of a mile where Shell Rock river flows close to the west edge of its valley and at the foot of the exposure. From a short distance below the railroad bridge it extends northward across the line into Kensett township. The following is the somewhat generalized section:

		FEET.
5.	Bowldery drift	2
4.	Badly weathered limestone, rusty red in color, no fossils, nodular in appearance, bedding obscure on account of disintegration	6

		FEET
3.	Fine textured limestone of light color, non-fossiliferous and containing much interstitial crystalline calcite, heavy bedded	3
2.	Slightly argillaceous magnesian limestone, grading downward into the darker variety, breaks with earthy fracture, but is very hard, bedding 8 to 12 inches	2 - 3
1.	Argillaceous dolomite, that portion not adjacent to joint or bedding planes a dark blue, good building stone, to water.	6

No. 4 of this section is the equivalent of the upper member in the Foster mill section. Below the railroad bridge a layer of calcareous sandstone eight inches thick appears between Nos. 3 and 2. This is very susceptible to the weathering agencies, and its breaking down forms a re-entrant in the quarry face.

A small quarry has been opened in the northern part of section 14, Kensett township, and some stone removed to supply a local demand for the purpose of rough masonry. The argillaceous dolomite has here been quarried to a depth of six feet. A thin layer of sandy, shaly and weathered limestone occurs between strata of the dolomite. All the layers shown at this exposure have suffered more or less from weathering and are of little value as building material.

At Fertile an outcrop in the south bank of the stream, below the wagon bridge, gives the following section:

		FEET.
3.	Hard limestone, badly shattered into small blocks by weathering	4½
2.	Arenaceous shaly limestone, very slight effervescence with dilute HCl	8
1.	Heavy bedded, sub-crystalline, dolomitic limestone, to water level	5

Bed No. 2 gives way much more readily to weathering than the other members and is conspicuous as a re-entrant along the face of the exposure. A small amount of stone has been quarried at the east edge of the town in a low terrace to the north of Lime creek.

The quarry industry of Worth county has been developed only to the extent of supplying a local demand in the immediate vicinities of the exposures of the limestone beds. Practically all that has been used for building purposes has been from the compact, light colored stratum and the underlying dark magnesian layer given in the sections along the Shell Rock. The former is well suited for road material and concrete work, while the latter, which is the equivalent of the Mason City dolomite, is considered one of the best and most durable building stones taken from the several quarries in Cerro Gordo county. This stone is well exposed to a thickness of ten to twelve feet in the northern part of Lincoln township, where the Chicago Great Western crosses Shell Rock river, and in a location where conditions are favorable for development.

These limestones also both produce an excellent quality of lime as demonstrated by their long continued use for this purpose at Mason City. The dolomitic stone gives a stronger lime than the white and one which deteriorates less rapidly by air slaking. The white lime, however, is eminently suited for use in the manufacture of sand-lime brick besides various mortar purposes. In this phase of the quarry business, Worth county has resources equal to any of its neighboring counties.

The Kinderhook.

The Kinderhook is typically developed in the vicinity of Burlington in Des Moines county and comprises a series of shales below and limestones above, separated by finely arenaceous deposits. The shales constitute the most extensive member at Burlington, exceeding one hundred feet in thickness but thinning northwestward along the line of strike, while the limestone member becomes relatively more important. The medial sandstone is fairly persistent but becomes less important northward. The calcareous member shows a decided tendency to become oölitic and ranges in texture from a compact brittle limestone to sub-crystalline and oölitic characters. It is equally variable in composition, showing all gradations from a pure limestone, as the oölite in Marshall county and the white limestones in Hardin and Humboldt counties, to the sugary brown dolomite of Hardin county. The quarry stone comes from the upper member, which has been extensively exploited in Marshall and Hardin counties. The shales are of interest as a possible source of Portland cement materials. They are extensively developed at Hannibal, Missouri, by the Atlas Portland Cement Company. The sandstone is not being developed at the present time although it has been quarried in a small way in Marshall and Tama counties.

DES MOINES COUNTY.

The Kinderhook beds are believed to form the country rock under the Mississippi bottom lands along the entire east front of the county. They appear near the base of the bluffs, overlain by the heavy Osage, or Augusta limestones, for practically the same distance and for about six miles up the Skunk river. They present their maximum exposure in the city of Burlington at Prospect Hill, and at Cascade in the bluffs and in the pit of the Granite Brick Company. According to Keyes, and Weller, the Kinderhook section at Prospect Hill is as follows:

SECTION AT PROSPECT HILL, BURLINGTON.

		FEET.
12.	Loess	15
11.	Till; yellowish brown clay, with pebbles and small bowlders.	8
10.	Limestone, white, thinly bedded	10
9.	Chert and siliceous shales with thin, irregular limestone beds, white and red in color	20
8.	Limestone, brown and white, rather heavily bedded, coarse-grained, sub-crystalline; becoming more thinly bedded and cherty above	25
7.	Soft, buff, gritty limestone	3-5
6.	White oölitic limestone	2-4
5.	Fine-grained, yellow sandstone	6-7
4.	Fine-grained, compact, fragmental gray limestone	12-18
3.	Thin band of hard, impure, limestone filled with Chonetes; sometimes associated with a thin oölite band	½-¾
2.	Soft, friable, argillaceous sandstone, sometimes harder and bluish in color, filled with fossils in the upper portion, the most abundant of which is *Chonopectus fischeri*	25
1.	Soft blue argillaceous shale (exposed)	60

Number 7 is somewhat earthy and magnesian and ordinarily is not sufficiently indurated to be used as a quarry rock. In the Government quarries below Cascade it has been taken out for use in the river improvement work. The oölite is not constant in thickness but ranges from one and one-half to four feet. It is usually fairly massive and compact and when properly selected has proven satisfactory as a dimension stone. It appears to be persistent as it has been seen along Flint river and south as far as Patterson. Numbers 2 to 4 inclusive are usually not sufficiently indurated to be used as quarry stone. Number 4 especially is oftentimes very friable and is to some extent a source of building and molders' sand. The shale is by far the most im

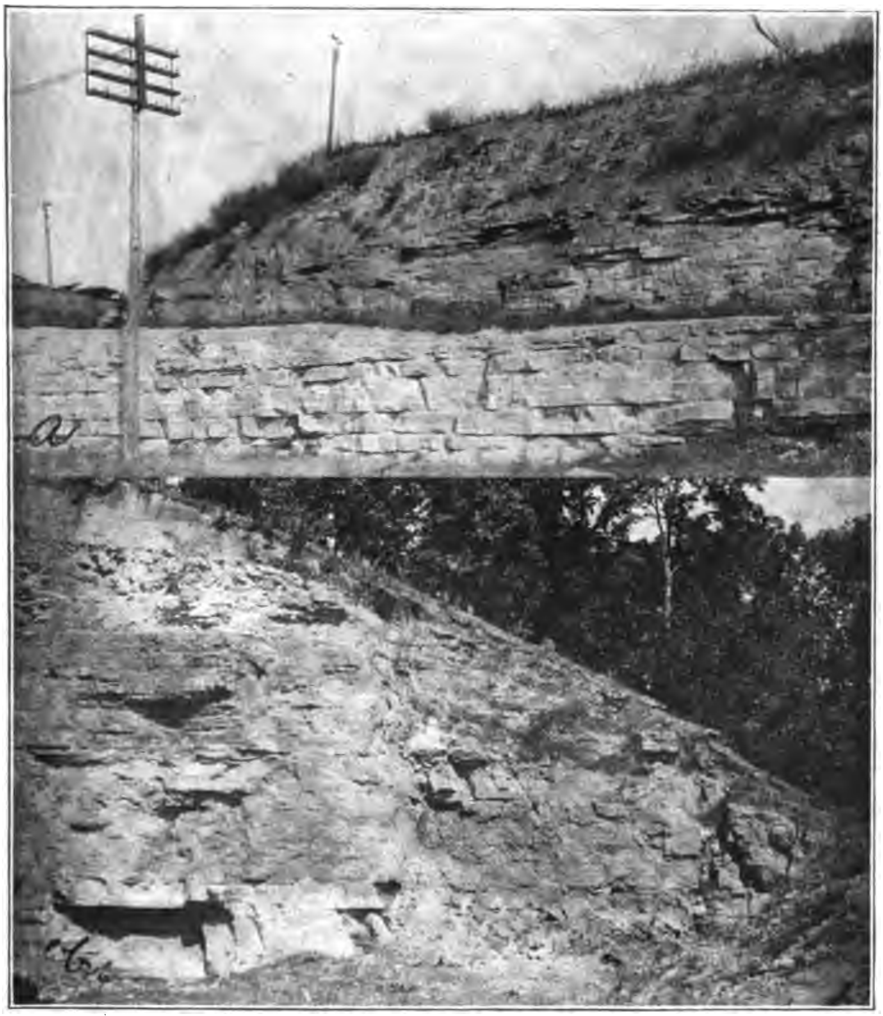

PLATE LII.—a. Section at Union Depot in Keokuk showing chert beds.
b. North end of Government quarries below Burlington showing the Kinderhook limestone.

portant member from a geological and also from an economic standpoint. It is a massive deposit ranging from blue to blue-gray in color, almost gritless. The beds are almost non-fissile, high in silica and comparatively low in alumina. They show an increase in silica upward and grade almost insensibly into a soft argillaceous sandstone above. The shale shows a maximum exposure of sixty feet and is known to extend at least one hundred feet below the water level in the river. Average samples were selected from the upper and lower portions as exposed in the pit of the Granite Brick Company at Cascade. The results are given below:

	Top of Pit.	Bottom of Pit.
Silica	77.39	71.78
Alumina	5.16	11.41
Ferric oxide	2.40	3.35
Lime	3.65	3.18
Magnesia	3.13	3.80
Potash	1.44	0.86
Soda	2.79	0.78
Sulphur trioxide	1.30	1.25
Loss on ignition	2.90	3.69
Moisture at 100° C	0.13	0.42

At Hannibal, Missouri, the Kinderhook shales are used extensively in the manufacture of Portland cement, and there is no good reason why the beds in the vicinity of Cascade are not suitable for the same purposes. Their area of outcrop above the river flood plain is very limited, but occasional areas, such as along the lower course of Flint river, are available.

The non-resistant character of the Kinderhook beds is in very large measure responsible for the steep bluffs which face the Mississippi river and larger tributaries.

FRANKLIN COUNTY.

The Carboniferous rocks present in the county belong to the Kinderhook stage. In the eastern portion of the county, beyond the border of the Wisconsin drift, Kinderhook rocks are exposed along the channels of all the principal streams. The rocks of this stage consist in this county of limestones and shales, the former varying from soft, marly, argillaceous beds containing large quantities of chert, to compact, partially crystalline, fossiliferous or semi-oölitic dolomite. The shales range from magnesian and calcareous beds which in many instances represent the firmer limestones in a state of decay, to typical yellow or bluish plastic clays.

Weathered Kinderhook limestone appears along Bailey creek in Richland township. Along Otter creek these beds are also exposed almost continuously from section 30 of Ross to its union with Hartgrave creek in Ingham township. One mile west of Chapin at the southwest corner of section 29, limestone is quarried. The following section may be viewed:

		FEET.
3.	Thin drift soil	1
2.	Badly weathered and iron stained argillaceous limestone	7
1.	Regularly bedded blue-gray to sugary-brown dolomitic limestone, containing Orthothetes, related to *O. inequalis* Hall, and Orthis (?), exposed	8

This quarry is worked by Mr. Wm. Low. A quarry face eight to ten rods in length is open. The usable portion of the section is covered by six to eight feet of argillaceous weathered rock which must be removed by stripping. The lower beds are regular and the individual layers vary from six to eighteen inches in thickness. The stone is granular and fossiliferous and ranges from brown to blue-gray in color. It yields readily to shaping for dimension work and affords the most durable building stone now produced in the county. A moderate local demand is supplied, none as yet being shipped.

Ledges of this rock form the east boundary of Otter creek valley and appear for some distance both north and south on both sides of the stream. Outcrops are to be found in the vicinity of Buffalo creek in section 36 of Richland township, and section 31 of Ross; it is also found along the west side of section 6, and across sections 5 and 4 of Mott township, where the bordering hills are all supported by the limestone, which stands twenty-five feet above the stream. Throughout the remainder of its course in Mott and Ingham townships, Otter creek valley is bounded by limestone walls, and evidences of the presence of limestone are to be seen, aside from natural outcrops and hillside talus, on nearly every section line where the public highway crosses this creek.

Limestone is also found along Spring creek in sections 21 and 22, and along Squaw creek in the city of Hampton. Stone has long been quarried in the north part of the town. A poor grade of limestone is now being used from a new opening a few hundred yards west of the cemetery. This opening shows the following section:

		FEET.
3.	Earthy, shattered and iron stained limestone with numerous bands of chert	5
2.	Thin-bedded, earthy limestone permeated with chert in bands and irregular concretions; somewhat cavernous, brachiopod impressions preserved in chert	6½
1.	Heavier beds (6-8 inches) and less chert, caverns lined with botryoidal calcite	7

The rock is weathered and contains intermittent bands of chert, which cause it to break very irregularly. It is used for only the rougher masonry work and would not give satisfaction in exposed positions.

There are innumerable exposures of the lower limestones, and occasionally of the shaly beds, not in the immediate vicinity of the streams, in the north-central part of Ingham and in the corners of Mott and Ross townships, where the main features of the topography are expressed in these older rocks. In the northeast quarter of section 28, Ingham township, south of the railroad track, a small quarry is opened on the land of D. W. Mott. The sequence is:

		FEET.
3.	Soil and decayed limestone	4
2.	Plastic, light blue shale with very thin bands of limestone	2
1.	Fossiliferous, crystalline brown dolomitic limestone, exposed	8

The beds are much rifted horizontally and fractured by vertical joint planes.

On Mayne creek, the greatest thickness of beds is to be seen near the north side of section 21, Reeve township. The section is partially obscured by talus materials, but it is approximately as follows:

		FEET.
8.	Drift	8
7.	Thinly bedded shattered limestone with much chert in oval nodules and more or less persistent bands	14
6.	Heavier bedded, arenaceous limestone, carrying chert as above, and occasional caverns and calcite geodes	6
5.	Shaly limestone with bands of firmer rock	12
4.	Compact, resistant ledge of limestone	1
3.	Argillaceous limestone containing some chalky appearing chert nodules grading into No. 2	2
2.	Firmer but weathered and iron stained limestone	1½
1.	Compact, evenly bedded dolomitic limestone	3½

Judging from its lithologic character, No. 1 appears to be equivalent to the rock quarried one mile west of Chapin. In the southwest quarter of the southeast quarter of section 10, Geneva township, just east of the wagon bridge over Mayne creek, is a quarry belonging to Mr. Oren Benson of Geneva, which exposes beds as follows:

		FEET.
4.	Soil	1½
3.	Weathered magnesian limestone with abundant small flint nodules	5½
2.	Heavy bed showing no lines of separation; brown where weathered and fossiliferous (Productus bearing long spines being very abundant); interior of large blocks, light in color or mottled by pink interstitial calcite, distinctly oölitic in texture	10
1.	Calcareous shale resting on limestone	1

A few feet below the base of this quarry and eight feet above the water in the creek the top of the impervious shales is marked for some distance eastward along the south side of the valley by a line of springs. The drift covering is very thin and the limestone forms a ridge extending eastward into sections 11 and 14. In a quarry near the north boundary of section 14, on the land of Mr. H. H. Andrews, the same succession of strata may be observed as noted above in section 10. The beds are here broken by vertical jointing which in places has produced open fissures six to eight inches in width. Unweathered samples of the lower stratum show an abundance of crystals of iron pyrite. The limestone rests on yellow shale which is exposed in the trench cut by a small stream a few hundred yards from the quarry.

The Kinderhook limestone is removed for local use at a large number of other points in Ingham, Geneva and Osceola townships, but at the above mentioned two localities only have quarry openings been made of sufficient extent to show the nature of the unweathered rock. Away from the weathered parts the rock is light in color and compact, and resembles in general appearance the Bedford stone. In natural outcrops this bed separates into numerous laminæ, each a few inches thick, but where newly exposed, slabs of almost any desired size can be obtained.

A small amount of stone is removed each year from these quarries. It is believed that continued development might open up unweathered portions of the bed which would furnish very good building stone. It seems likely also on account of the extreme thinness of the drift that prospecting along Mayne creek in this vicinity would discover places where it would be possible to obtain desirable stone that is not buried beneath so great a thickness of weathered residuum which must be removed.

GRUNDY COUNTY.

Grundy county is covered by a thick mantle of glacial debris and the only exposures of indurated rock known appear along Wolf creek near the southern border. The only quarry worthy of the name is located just south of the Chicago and Northwestern Railway depot in Conrad, on the south bank of Wolf creek. The following section is exposed:

CONRAD SECTION.

		FEET.
5.	Drift (modified Kansan probably)	5
4.	Limestone, residual, consists chiefly of cherty concretions embedded in a matrix of greenish clay streaked and mottled with ferruginous and marly material	3
3.	Limestone, slightly oölitic, composed essentially of a shell breccia almost identical with No. 1, in the Eagle City section in Hardin county	4
2.	Limestone, hard, sub-crystalline, containing numerous brachiopod casts	2
1.	Limestone, typical oölite in heavy beds; a Straparollus and a turreted form of gastropod were noted, also numerous brachiopod casts	5

The base of the section is about four feet below the Chicago and Northwestern railway track and 1,010 feet above tide.

The beds exposed here may be correlated with the upper oölite in the Marshall county sections exposed in the quarries at Rockton, Quarry, LeGrand and Timber creek, and also in the Eagle City section in Hardin county. The Conrad quarry has been operated more or less continuously for a number of years. The limited outcrop and rapid thickening of the drift compels one to conclude that the quarry industry will never attain much development in the county.

HARDIN COUNTY.

While the Kinderhook beds are supposed to comprise the country rock over a considerable portion of the surface in Hardin county, good exposures are confined to the immediate vicinity of the Iowa river from Gifford south to the county line, and from Eagle City to Alden. Quarries have been opened at several points, notably at Gifford, Eagle City, Iowa Falls and Alden. Only those at the two latter places are, or promise to be, of more than local importance. The beds exposed exhibit two well marked facies; an upper brown, earthy to sugary dolomite, and a lower white to gray limestone. The latter often contains layers semi-oölitic in character above and argillaceous to arenaceous below. At Iowa Falls there appears to be a decided arching up of the strata and a maximum section of eighty feet is exposed in the river gorge. The limestone beds are known to rest on shales or arenaceous shales believed to be continuous with those which outcrop along the Mississippi river at Burlington and which underlie the limestone series in Marshall county. The section exposed along the river and along Rocky run, its leading tributary, at Iowa Falls, is given below and comprises one of the most important Kinderhook sections in central Iowa.

IOWA FALLS SECTION.

		FEET.
6.	Drift, reduced to a heterogeneous mixture of bowlders and fragments of country rock at the face of the escarpment but thickens greatly in the bluffs. Considerable areas are practically without a drift covering	0-80
5.	Dolomite, brown, saccarhoidal, heavy-bedded below, but thinner-bedded and much shattered above; often exhibits an earthy fracture when weathered. Numerous casts of *Straparollus obtusus* present in places	20-30

		FEET.
4.	Limestone, light gray, composed largely of shell breccia and containing a brachiopod fauna; has a mealy appearance, but on close inspection is found to be but slightly oölitic...	5
3.	Limestone, gray-brown, is finer textured, more compact and evenly bedded than the above......	3
2.	Limestone, light gray; weathers white and so appears in the gorge walls, exhibits a conchoidal fracture and is heavy-bedded..	5
1.	Limestone, shaly to slightly arenaceous in certain layers, in places forms a slight re-entrant in the cliff walls; exposed above water level..	5-10

The most important quarries are situated east of town on the river. The Ellsworth Stone Company is operating a quarry on the northeast side of the river, which was formerly known as the Biggs quarry. The sequence of beds is as follows:

THE ELLSWORTH STONE COMPANY'S QUARRY SECTION.

		FEET.
6.	Drift, very thin; consists chiefly of a bowldery gravel.........	0-3
5.	Dolomite, brownish buff, much weathered in places and presents an arenaceous or earthy facies.......................	4
4.	Limestone, white, oölitic, fossiliferous.......................	6
3.	Limestone, blue, compact, of firm texture and very brittle ...	3
2.	Limestone, white, lower three feet very compact and brittle; fracture conchoidal to uneven, contains numerous blebs of crystalline calcite; almost lithographic in texture	5
1.	Limestone, gray, dolomitic, very slightly arenaceous to argillaceous, exposed..	5

The usual method of quarrying is to drill deep holes vertically nearly parallel to the face of the cliff, and then to use heavy charges of explosives to shoot loose the ledges. An ordinary churn drill is used with a traction engine for power. This leads to great shattering, and scarcely more than thirty per cent of the entire section can be used for dimension stone. A large proportion of the remainder was formerly considered to be waste material and was thrown into the river. This was true not only of the quarries here, but of those near Alden. At the present time a large crusher of the Gates type has been installed and the entire assemblage of beds is utilized. In fact, dimension stone and rubble stone are only incidental products in the production of the various grades of crushed stone.

Southwest of the Ellsworth plant, on the opposite side of the river where the river turns toward the east, the Barber Asphalt Company has opened a quarry and installed a modern crusher plant. The beds developed are similar to those in the preceding section, but higher in the series. The principal part of the section being developed at the present time consists of earthy dolomite which affords an inferior grade of crushed stone.

West of Iowa Falls the Lower Carboniferous rocks are much more rifted and shattered than to the eastward, and the limestone layers become sub-crystalline in texture. The stone takes a good polish, possesses a pleasing color, and if large blocks could be obtained, the rock would possess great value for ornamental and structural purposes. Unfortunate it is that the same agency which produced the partially crystalline structure, so essential in marbles, was also responsible for the shattering and rifting of the beds. In fact the marbleization was rather a result of the rough usage to which the beds were subjected. The beds continue shattered and sub-crystalline in texture to the point of their disappearance beneath the drift at Alden. Formerly the Ivanhoe Quarry Company put in a steam crusher and operated quite extensively near the C. and N. W. railway tracks on section 16, in Hardin township. The building containing the machinery burned down, and the plant has long since been dismantled and abandoned. The beds exposed at this point are as follows:

IVANHOE SECTION.

		FEET.
3.	Drift (of great depth in the bluff)	0-3
2.	Limestone, grayish white, sub-crystalline, very hard and much shattered; thinly bedded	20
	Apparently a local unconformity.	
1.	Limestone, much disintegrated and cavernous. In places a residual clay appears between 1 and 2. Surface very uneven, exposed	6

Westward from the Ivanhoe quarries to Alden, the river flows between low limestone walls varying from ten to thirty feet in height. These limestone barriers are almost cut out in one or two places by Coal Measure outliers. In Alden the beds greatly resemble a portion of the Ivanhoe section. The beds are as follows:

ALDEN SECTION.

	FEET.
3. Drift, as in previous sections, is thin at the face of the scarp; a number of large granitic bowlders were noted	3
2. Limestone more or less evenly bedded, appears to be lithologically the same as No. 1; a marly or shaly band separates 1 and 2 generally	12
1. Limestone, light gray, hard, sub-crystalline and oölitic in texture. The lower four feet show marked cross-bedding; false beds dip to the southwest; the upper surface is somewhat undulating and dips gently to the south	5

Here, as in the preceding exposures, the beds are much rifted and shattered. Individual layers rarely exceed four or five inches in thickness, and two well developed series of fissures are visible. The fissures of the major series trend north and south, and are apparently parallel to the corrugations, while those of the minor series stand approximately at right angles to the folds. Genetically the two series probably form but one great system and were formed at the time of rock crushing.

North of Alden, the indurated rocks dip rapidly and were not observed beyond the corporate limits of the town.

Eastward of the Falls limestone ledges are more or less continually present to Eagle City where the following section is exposed:

	FEET.
5. Drift, exposed	5–10
4. Dolomite, yellowish brown, much shattered where viewed; contains a few siliceous nodules	10–25
3. Limestone, gray, sub-crystalline and semi-oölitic	1½
2. Dolomite, yellow to gray, sugary	3
1. Limestone, gray, oölitic; very similar to the Bedford oölite in texture, and also to the oölite exposed at Conrad, in Grundy county	4

The base of the section is about five feet above low water in the river. These indurated beds support a bench which rises forty or fifty feet above water level and continues some distance on either side of the wagon bridge. Beyond Eagle City, the beds disappear rapidly and the surface outcrops of the Kinderhook beds are almost entirely obscured by glacial debris and Coal Measure talus. At Hardin City, Steamboat Rock and one or two points between, No. 4 of the Eagle City section is visible and rises some six or eight feet above the water level. In all cases it is greatly weathered and shattered, making its identity difficult to establish. Between Steamboat Rock and Eldora, the Lower Carboniferous passes entirely below the stream channel, but rises again immediately south of the wagon road bridge at Eldora. Going down stream from the Eldora bridge a weathered dolomite appears in the stream-bed and also in the right bank about sixty rods below the road crossing. The ledges rise eight feet above the water and appear to be identical, both lithologically and faunally, with the upper member at Iowa Falls. These beds appear more or less interruptedly from this point to Union, forming low benches on one or both sides of the river. At Xenia, and again between Gifford and Union, the white limestone member is visible. The maximum exposure is south of Gifford, near a small stream which enters the Iowa from the west. The beds exposed to view are:

		FEET.
4.	Drift and wash	0-3
3.	Limestone, light gray; white when weathered	0-8
2.	Dolomite, yellowish brown, much shattered and unevenly bedded	6-8
1.	Dolomite, red-brown, heavy but unevenly bedded, exposed	4-6

Numbers 1 and 2 are, in a sense, complementary. Where one thins the other thickens and the two aggregate twelve feet exposed. Not the slightest trace of organic remains could be found. Southward and southeastward the beds are cut out within 100 yards by the Coal Measure shales only to come into view again a quarter of a mile down the branch on the terrace of the Iowa. Beyond Union the Kinderhook beds are carried below the river, but reappear west of Liscomb in Marshall county.

HUMBOLDT COUNTY.

The Kinderhook limestone beds outcrop near the Minneapolis and Saint Louis railway in the southern part of the city of Humboldt and present an almost continuous exposure on the river for more than a mile. The same beds outcrop near the Chicago and Northwestern railway north of the city, and near Rutland about five miles to the northwest. The section exposed below the dam in Humboldt is given below:

		FEET.
4.	Alluvial wash, variable in thickness; on top of terrace about	3
3.	Limestone, oölitic, rather coarse-grained, gray to white......	10
2.	Limestone, compact, gray-white, a gradation from No. 1, but fewer fossils present and apparently less brecciated....	2
1.	Limestone, brecciated and filled with casts of fossils, chiefly brachiopods, very compact and brittle in outcrop; bedding planes not apparent; exposed above low water..............	4

The section rises toward the town and the oölite probably shows a greater thickness than is indicated in the above section. All of the beds dip perceptibly up stream. An average sample was taken from the above section and analyzed. The result is given below:

Insoluble..	0.50
Iron oxide and alumina..	1.12
Calcium carbonate..	97.20
Magnesium carbonate..	2.00
Total..	100.82

Analyzed by A. O. Anderson, from sample collected by C. M. Morgan.

At Rutland, along the south bank of the river, is one of the most conspicuous rock exposures in the county. The section exposed here is correlated by Macbride with the lower beds in the Humboldt section. The ledges are nearly in horizontal posi-

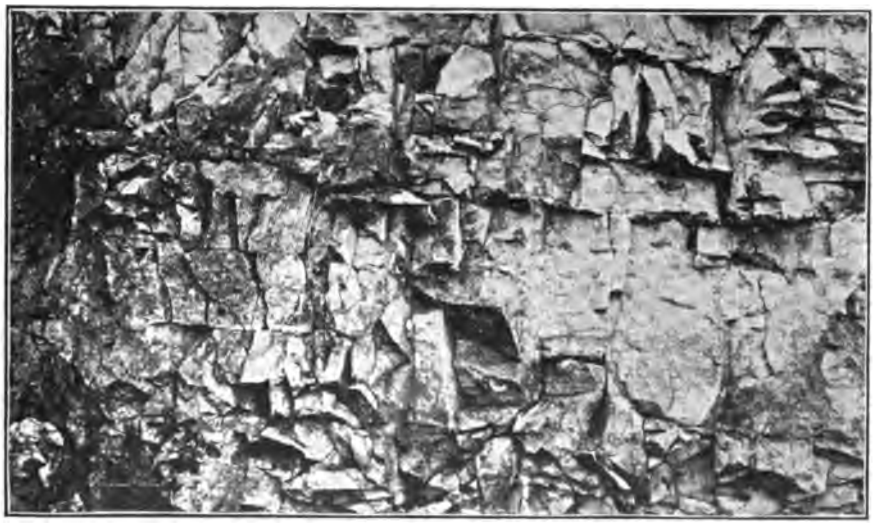

FIG. 28.—Shows "chipstone" weathering characteristic of the compact layers in the Kinderhook limestone in Humboldt county. (Photo by Macbride).

tion, attain a maximum of twenty feet in thickness, and can be traced about one mile east where they disappear. Westward they give place to the Saint Louis in section 23 in Avery township. Outcrops apparently referable to the same horizon are known at other points in Rutland township. The bedding planes in the Rutland limestone are not very apparent. The rock breaks up into irregular sharp angled spalls and is very hard.

The Kinderhook limestone was used formerly in the manufacture of lime for local use, but no lime is produced at the present time.

MARSHALL COUNTY.

The Kinderhook immediately underlies the drift over the northeast one-third of Marshall county, and extensive outcrops may be viewed along the Iowa river in the vicinity of Quarry and LeGrand, along Nicholson creek at Rockton, and on Timber creek, about two and one-half miles southwest of Quarry. All of the leading exposures are near the trunk lines of railway which cross the county, and all are connected by switches extended from these lines.

In the southeastern portion of the state, there are extensive outcrops of the Kinderhook, notably at Burlington, which consist of shale, fine-grained sandstone, and sub-crystalline limestones, of which the first and last members are the most important. In Marshall county, the calcareous beds greatly predominate. Five fairly well defined divisions can be recognized readily, the lowest member of which is a shale which resembles the shale member in the pit of the Granite Brick Company, at Burlington. This is overlain by a fine-grained, blue to gray calcareous sandstone which is in turn followed by beds of oölite. Above the oölite, cherty magnesian limestones are present in considerable thickness, and completing the section are the brown to gray sub-crystalline limestones.

The Kinderhook shales are not exposed in Marshall county, but are present in well sections which penetrate the indurated rocks. The basal member exposed is the fine-grained sandstone which appears only in the eastern portion of the county. The leading quarries develop the oölite and the magnesian limestone, although all of the members above the shale have been exploited to some extent. The most extensive section in the county is exposed north of LeGrand, near the Iowa river. The following sequence of beds may be observed at this point:

		FEET.
18.	Loess, interstratified sands and silts below	16
17.	Bowlder clay oxidized a deep brown and containing bowlders much decayed	5–10
16.	Limestone, sub-crystalline, pebbly	3
15.	Oölite fine-grained, with many brecciated grains	4
14.	Limestone, gray, slightly oölitic	2½
13.	Limestone, gray above and yellow below	2
12.	Limestone, buff, magnesian, rather heavily bedded, bisected by chert band about four feet from the base	9
11.	Limestone, mixed gray, blue and buff, breaks very irregularly ("Brindle" of the quarrymen) really an intra-formational conglomerate	3½
10.	Chert	½
9.	Limestone, soft, yellow, arenaceous; in thin layers; earthy in places	2½
8.	Chert	½
7.	Limestone, blue, variegated to yellow-brown	6
6.	Chert	½
5.	Fossil-breccia with lenses of crystalline calcite	1
4.	Limestone, buff, magnesian, fine even texture and massive; cherty concretions scattered promiscuously throughout. One quite persistent band of chert about four feet from the base	12
3.	Limestone, blue, variegated to brown, hard, conchoidal fracture, in heavy layers	3½
2.	Oölite, in layers 14, 12, 8, 9, 6, 36, 26, 24 and 42 inches in thickness	15
1.	Sandstone, fine-grained, blue, calciferous, in part shaly, exposed	10

The beds dip gradually to the southwest, and as the ground rises in that direction, are soon carried below the surface of the river. Near Indian Town in Tama county, the base of the oölite lies more than twenty feet above the water level. At the northeast quarry above LeGrand, it is about ten feet above the water level, while in the west quarries, both the oölite and the sandstone lie below the bed of the river. At the west quarry, the upper members in the above section are better developed. Number 16 shows a thickness of about twelve feet. At Rockton only numbers 14, 15 and 16 are exposed, and the beds are more shattered and weathered than their equivalents in the LeGrand quarries. The section exposed near the Iowa Central railway is second only in importance to the Quarry and LeGrand sections. The beds exposed are as follows:

		FEET.
8.	Loess, sandy below	10
7.	Bowlder clay (Kansan)	6
6.	Limestone, brown, sub-crystalline, thinly bedded, and rubbly above, heavier below	8
5.	Limestone, yellow, brittle, with occasional small caverns decorated with concretionary calcite	1½
4.	Limestone, blue, hard, brittle	2
3.	Oölite in three layers, 8, 22 and 6 inches respectively	3
2.	Limestone, gray-brown, with layers of blue, sub-crystalline limestone interbedded	6
1.	Limestone, gray-blue, close textured, soft when first exposed, weathered portion, yellow; layers vary from 6 to 18 inches, very evenly bedded, magnesian	12

The oölite in the Timber creek section is undoubtedly the equivalent of the oölite exposed at Rockton, and the upper oölite of the LeGrand section. Numbers 1 to 6 in the Timber creek section find their counterparts in 12 to 16 in the LeGrand section, with the possible exception of Number 5, which was not certainly recognized farther north and east.

The differences in physical properties and coloration are largely if not wholly due to differences in the weathering. The Timber creek beds are in large part below the water level, and the prevailing colors of the beds developed are shades of blue and gray, while the tones of yellow and buff which prevail in the east quaries at LeGrand are believed to have been brought about through the action of weathering agencies. The hardness of the Timber creek stone increases materially on exposure.

Kinderhook beds are also exposed northwest of Liscomb, near the center of section 2.

QUARRY INDUSTRY.

The Kinderhook beds have been exploited mainly in the vicinities of Quarry and LeGrand, and Timber creek. Quarries were operated formerly at Rockton, but have been abandoned for some years. Stone has also been taken out along the river, near Liscomb, for local use only.

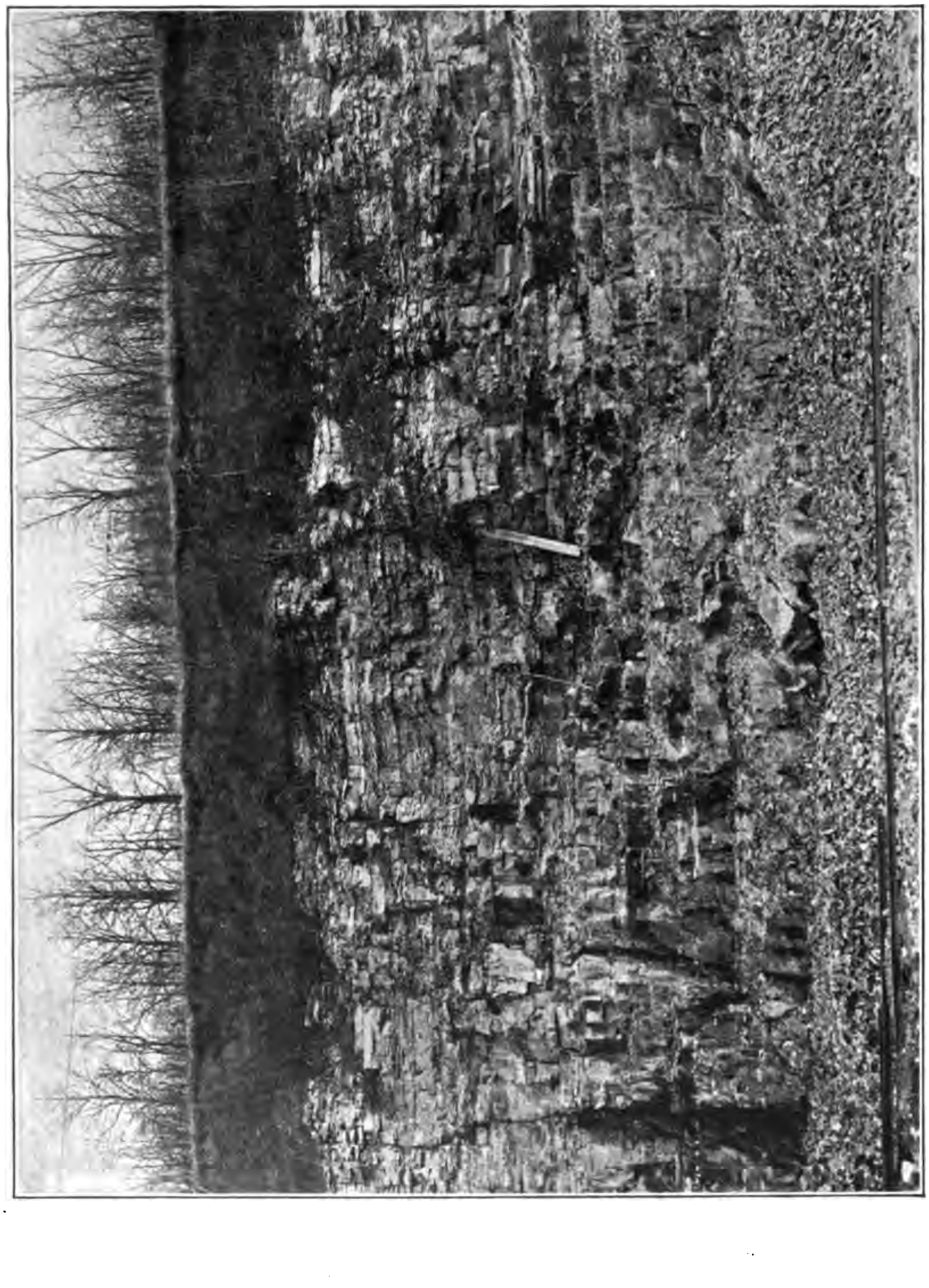

PLATE LIII—Typical section in quarry of LeGrand Quarry Company, Quarry, Marshall county, Iowa.

LE GRAND QUARRY COMPANY.

The pioneer in the quarry industry, as well as the largest company operating in the county at the present time, is the Le Grand Quarry Company, with its central office in Marshalltown. The company owns and operates quarries at Quarry and Timber creek.

Quarry. Three quarries are connected with the C. & N. W. railroad, by branch lines at this point. Active operations were begun as early as 1860, when a limited quantity of building stone and lime was produced. Two years later the railway tracks were extended into the quarries, and the company has operated continuously ever since. The manufacture of lime was discontinued some years ago.

The quarry plant is provided throughout with the most approved machinery. The equipment consists of a steam crusher, gang mills, steam drills, derricks, lathes and planers; and quarrying and stone working are carried on according to modern methods. The LeGrand beds in their entirety have been exploited to some extent, though the position of the blue sandstone renders it almost unavailable at present. (See LeGrand section.) The oölite and upper magnesian limestone layers afford the most valuable products, although the chert beds and shattered limestones along with the debris consequent to quarry operations, are worked up into riprap, concrete, railway ballast, etc., and constitute an important source of revenue to the company.

The chief building stones put upon the market are known commercially as oölitic limestone, Iowa marble, Iowa caen stone, and blue limestone.

The basal blue sandstone has not been sufficiently explored and tested to warrant definite statement as to its merits as a structural material. Small quantities of the stone have been removed from the east quarries and used as paving in the streets of Marshalltown with some promise of satisfactory results.

There are two grades of oölitic limestones. The lower layer measures three and one-half feet in thickness and is coarse grained. The upper twelve feet is of finer texture and consists of layers of the following thicknesses, respectively, from below upwards: 24, 26, 36, 6, 9, 8, 12, and 14 inches. The oölite is quarried only at the two east quarries, the dip of the beds and the slope of the river carrying the layers below the bed of the stream before the west quarry is reached. Formerly, the coarse, heavy basal layer was used for constructional purposes, but of recent years, experience has demonstrated that it suffers disintegration when exposed for a season to atmospheric conditions. The fine-grained layers are close, even-textured, and stand the test of time well. This is shown not only in artificial structures where the blocks have maintained their angularity against sunshine and storm for more than a quarter of a century, but better still in the natural exposures where these layers stand out in bold relief. The oölite is composed of small, rounded, concretionary calcareous grains embedded in a semi-crystalline matrix of cementing material of the same composition. Many of the concretions contain small angular siliceous grains. The unaltered rock is of a gray-blue color, while the weathered portion assumes a yellowish hue. Certain of the layers are highly fossiliferous, and take a high polish. This variety is known commercially as fossilite marble, and is much prized for interior decorative purposes. Such slabs need to be selected with some care, for small grains of iron pyrite are often present and produce brown stains when exposed to the weather.

The upper portion of the magnesian limestone furnishes both the Iowa "marble" and the Iowa carbonate "caen stone," the former containing a higher percentage of magnesia than the latter. The Iowa marble occurs in heavy beds from two to three and a half feet in thickness. The unweathered or slightly weathered portions are plain, light buff in color, while the weathered layers are of a deeper color and beautifully veined with iron oxide. The stone receives a high polish, but like other limestones, does not retain it when exposed to atmospheric agencies. It is used extensively for paneling and all sorts of inlaid work, and gives good satisfaction when kept dry. It also makes a first class dimension stone.

The caen stone is similar in color to the marble, but it is softer, more tenacious and of lower specific gravity. It is especially adapted for carvings and moldings.

A ledge of blue limestone lies between the chert beds and the oölite and a similar ledge immediately overlies the chert beds. This limestone is very hard, compact and somewhat irregularly bedded, which renders quarrying and working rather difficult. The stone is used to some extent as a coursing stone and is very durable, but its intractable character renders its production expensive, and it is used mainly for ballast and concrete.

The brown sub-crystalline limestone with its interstratified oölitic layers affords some good dimension stone and would be considered desirable for foundations in regions where building stone is scarce, but by far the greater quantity is transported to the crusher.

Timber Creek. The LeGrand Quarry Company has also developed an extensive quarry in Timber creek. A side track is laid in from the Iowa Central railway and the plant is well equipped with modern machinery. The beds worked are the same as those at Quarry, from the magnesian limestone upwards. As has been mentioned, the magnesian limestone here differs in color from its homologue at Quarry and LeGrand. At the latter places shades of buff prevail, while at the Timber creek quarries the chief beds are a gray-blue with occasional layers in part light yellow. The fact is emphasized that the predominating color in the unaltered LeGrand beds is a gray-blue, which is changed to tones of buff and yellow through weathering agencies. Here as in other places, the magnesian layers succumb less readily to disintegrating forces than the associated beds, and as a consequence stand out prominently in natural quarry faces.

The upper oölite and brown sub-crystalline limestone are of more importance here than at the exposures along the Iowa river.

TESTS OF THE LEGRAND STONE.*

The principal varieties of the LeGrand stone were subjected to three series of tests, viz.:

1. Strength and ratio of absorption to determine the compactness of the stone, and hence its ability to withstand the atmospheric agencies.

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*The mechanical tests were made in large part by Messrs. G. W. Zorn and J. W. Elliott under the personal supervision of Prof. A. Marston, in the department of Civil Engineering of the Iowa State College. The chemical analyses were made for the Survey by Prof. G. E. Patrick.

2. Freezing and thawing alternately, and carefully noting the loss in weight and strength; and hence determining the tendency of the stone to disintegrate or weaken under the action of frost.

3. Chemical analyses to determine the relative amounts of desirable and deleterious constituents present.

The two-inch cube was used throughout because of its convenience in handling and as it is the unit generally adopted by investigators along this line. Great care was exercised in the preparation of the cubes in order to guard against the production of incipient fractures through the impact of tools and the consequent lessening of the strength. The blocks were sawed out with the diamond saw and then reduced to the proper dimensions by grinding. The results are tabulated in the subjoined tables.

TABLE I.

MECHANICAL TESTS.*

Number	Kind of Stone	Height of cube	Surface dimensions	Area	Breaking Load in Lbs.		Load Per Square Inch		Remarks
					Spalling began	Failure	Spalling began	Failure	
	†Oölite, fine-grained, northeast quarry..	2.03	1.98x1.99	3.94	......	46,680	......	11,600	Failure accompanied by much shattering.
4	do heavy bedded..................	2.02	2.00x2.00	4.00	47,500	53,800	11,875	13,450	do
5	do " "	1.97	2.00x1.98	3.96	54,000	59,300	13,636	14,900	do
6	do thinly bedded..................	1.96	1.96x1.96	3.84	39,400	39,400	10,260	10,260	do
22	Oölite, light, southeast quarry	2.05	2.00x2.04	4.08	42,000	52,000	10,280	12,740	do
23	do	1.97	2.00x2.00	4.00	57,000	57,000	14,250	14,250	do
43	do heavy bedded..................	2.00	2.00x2.00	4.00	38,000	53,000	9,500	13,250	do
	†Iowa marble, plain, west quarry......	1.98	1.98x1.97	3.90	......	47,120	......	12,080	All samples of the Iowa marble broke in such a way as to show much elasticity.
16	do	2.00	2.02x2.04	4.12	60,500	63,300	14,685	15,120	
	†Iowa marble, colored.................	2.00	2.02x2.01	4.06	......	37,060	......	9,128	
27	Blue limestone, northeast quarry......	2.00	2.02x2.02	4.08	......	......	......	......	63,000 lbs. applied, no effect.
24	do	1.99	2.00x2.02	4.04	......	......	......	......	63,000 lbs. applied, no effect.
11	Fossiliferous limestone, N. E. quarry..	2.00	2.00x2.00	4.00	42,000	......	10,500	......	Sustained 65,800 lbs. without further rupture.
12	do	2.00	2.00x2.00	4.00	63,300	......	1,582	......	Beyond capacity of machine to crush.
15	do..................southeast quarry	1.99	2.00x2.00	4.00	43,700	......	10,925	......	Sustained 65,800 lbs. without further rupture.
26	do	2.00	2.00x2.02	4.04	58,300	66,400	14,430	16,435	
28	do.......................west quarry	1.97	2.00x1.98	3.96	38,700	38,700	9,773	9,773	
33	Blue limestone, Timber creek.........	1.98	1.98x2.00	3.96	28,000	34,500	7,070	8,712	
34	do	2.00	1.98x2.00	3.96	29,000	33,200	7,320	8,383	

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*An Olsen testing machine was used in making these tests. The specimens were placed between two steel plates, the upper being fixed, while the lower was free to oscillate in a hemispherical protuberance, which fitted accurately in a well lubricated socket, thus distributing the pressure equally when the parallelism of the cube faces was imperfect. The load was applied at a uniform rate.

†Tests made under the direction of Prof. G. W. Bissell, Dept. of Mechanical Engineering, I. A. C.

TABLE II.

FREEZING TESTS.*

Number	Kind of Stone	Height of cube	Surface dimensions	Area	Breaking Load in Lbs.		Load Per Square Inch		Loss in weight in per cent	Remarks
					Spalling began	Failure	Spalling began	Failure		
20	Oölite, fine-grained, N. E. quarry ..	2.05	2.00x2.08	4.16	55,700	56,400	13,390	13,558	0.0014	Loud report.
21	do	2.08	2.00x2.08	4.16	26,000	....	6,250	14,280	0.0013	Sustained 59,400 lbs. Very slight spall at 26,000 lbs.
38	Oölite, fine-grained, S. E. quarry..	1.99	1.97x2.00	3.94	50,000	60,000	12,690	15,230	......	Loud report and cube much shattered.
44	do	2.00	2.00x1.96	3.92	34,000	55,700	8,673	14,210	......	do
46	do	2.02	1.97x1.97	3.88	50,000	56,500	12,890	14,560	......	do
19	Iowa marble, west quarry..........	1.96	2.02x2.02	4.08	50,000	56,500	12,255	13,850	0.0007	Broke with a loud report.
17	do	1.92	2.00x2.00	4.00	42,600	52,700	10,650	13,175	0.0008	do
18	do	2.00	2.04x2.02	4.12	38,000	51,700	9,225	12,550	0.0009	do
14	Blue limestone, northeast quarry...	2.00	1.98x1.97	3.90	....	....	....	15,360†	......	59,400 lbs. applied without effect.
3	Fossiliferous limestone, N. E. quarry	2.00	2.00x2.02	4.08	....	....	....	14,560†	......	59,400 lbs. applied without effect.
2	do	1.98	1.97x2.00	3.94	55,600	....	14,035	14,900†	......	59,400 lbs. sustained.
29	Fossiliferous limestone, west quarry.	1.98	2.04x2.02	4.12	35,900	40,000	8,715	9,710	......	Weak report.
30	do	1.97	1.99x1.96	3.91	30,500	35,000	7,800	8,950	......	do
32	Blue limestone, Timber creek	2.00	2.04x2.01	4.10	28,000	36,300	6,830	8,850	......	Slight report. ‡
45	do	1.96	1.98x1.96	3.88	32,700	32,700	....	8,430	......	

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* The cubes were placed in distilled water until completely saturated, after which the specimens were encased in cotton batting saturated with distilled water and placed in wooden trays, eight by eight inches and two inches deep, provided with wire bottoms. The trays after being securely packed were placed in the refrigerator and kept at a temperature of from 17° to 19° F. for 48 hours. Then they were removed from the refrigerator and subjected to a temperature of 70° F. for twenty-four hours. This process was repeated six times. The specimens were afterward subjected to refrigeration and thawing ten times; but the conditions were less constant than in the first six. In the later series the minimum temperatures ranged from 21° to 32° F.

† The above table shows that the blocks suffered no appreciable loss in weight or strength during the investigation. It is highly probable that lower temperatures would have given very different results.

‡ In spite of the apparent weakness, low specific gravity and rather high percentage of absorption, the quarry face along natural fissures shows this stone to be one of the most durable quarried in the county.

TABLE III.

ABSORPTION AND SPECIFIC GRAVITY TESTS.

Number	Name of Stone	Loss of Quarry Water Through Drying—Weight in Gs.			Water Absorbed After Immersion, Expressed in Percentages, over Dry Weights				Specific gravity	Weight per cubic foot in lbs.	Remarks
		0 hours	1 hour	5 hours	1 hour	3 hours	24 hours	144 hours			
20	Oölite, fine-grained, northeast quarry...	350.90	350.70	350.58	0.85	1.59	2.66	2.75	Average, 2.57	160.5 lbs.	
21	do..................................	348.91	348.79	348.63	1.56	3.26	3.95	4.05			
38	Oölite, south quarry	335.03	334.99	334.97	1.20	1.50	2.50	2.61			
44	do..................................	333.90	333.79	333.63	0.71	1.85	2.11	2.20			
46	do..................................	326.90	326.30	325.63	1.50	1.96	2.55	2.64			
19	Iowa marble, west quarry.............	323.10	327.70	322.47	2.33	3.02	3.60	3.87	2.54	153.2	Average.
17	do..................................	309.40	309.00	308.01	1.81	2.43	3.31	3.57	......	....	
18	do..................................	320.90	319.20	318.20	2.31	3.06	3.97	4.37	......	....	
10	Blue limestone, northeast quarry.......	348.70	348.21	348.19	0.48	0.86	1.86	2.02	2.77	173.0	
3	Fossiliferous limestone, northeast quarry	344.00	343.78	343.52	0.72	1.01	1.72	1.79	2.60	162.5	
2	do..................................	353.86	353.40	353.20	0.22	0.50	0.70	0.77	......	....	
30	Fossiliferous limestone, west quarry....	311.00	310.90	310.87	0.06	0.84	1.65	1.79	......	....	
29	do..................................	340.91	340.46	340.38	0.22	0.84	1.64	1.79	......	....	
32	Blue limestone, Timber creek	320.76	320.36	320.00	2.03	3.01	3.17	3.36	2.30	144.0	
45	do..................................	285.74	285.36	285.15	4.00	4.67	5.41	5.65	......	....	

TABLE IV.

CHEMICAL ANALYSES OF LEGRAND STONE.

Constituents.	Fine-grained oölite.	Blue limestone.	Iowa caen stone.	Iowa marble, plain.	Iowa marble, colored.	Stratified limestone.
Hygroscopic water (loss at 100° C.)	0.03	0.09	0.06	0.04	0.06	0.04
Combined water (expelled by ignition)	0.13	0.21	0.15	0.19	0.12	0.12
Silica and insoluble	0.77	0.96	1.24	0.80	0.89	1.22
Carbonic acid (CO_2)	43.62	43.30	43.79	44.85	44.76	43.85
Alumina (Al_2O_3)	0.05	0.07	0.18	0.14	0.15	0.14
Iron (Fe_2O_3)	None	None	0.15	0.15	0.31	0.26
Iron (FeO)	0.09	0.27	0.09	0.19	0.10	0.09
Lime (CaO)	55.05	54.85	50.56	45.42	45.39	50.42
Magnesia (MgO)	0.28	0.28	3.70	8.21	8.28	3.96
Manganese oxide (Calc. as MnO)	....	0.08	....	....	....	Trace
Phosphoric acid	....	....	Trace	Trace	....	....
Totals	100.02	100.11	99.92	99.99	100.06	100.10

PROBABLE COMBINATIONS.

Water	0.16	0.30	0.21	0.23	0.18	0.16
Calcium carbonate ($CaCO_3$)	98.30	97.95	90.28	81.11	81.05	90.04
Magnesium carbonate ($MgCO_3$)	0.59	0.38	7.77	17.24	17.39	8.08
Silica and silicates Alumina, iron oxide, etc.	0.95	1.37	1.74	1.42	1.38	1.72
Totals	100.00	100.00	100.00	100.00	100.00	100.00

TAMA COUNTY.

While the Kinderhook beds are believed to lie immediately beneath the drift over practically the entire county, outcrops are limited to a comparatively small area along the middle western border.

Essentially the same members which have been noted in the better sections at Quarry and LeGrand in Marshall county are exposed in Tama county, but in Tama they are more weathered. The Stevens quarry near the southwest corner of section 8 of Indian Village township, about one and one-fourth miles west of Butlerville, may be taken as fairly typical. The section is as follows:

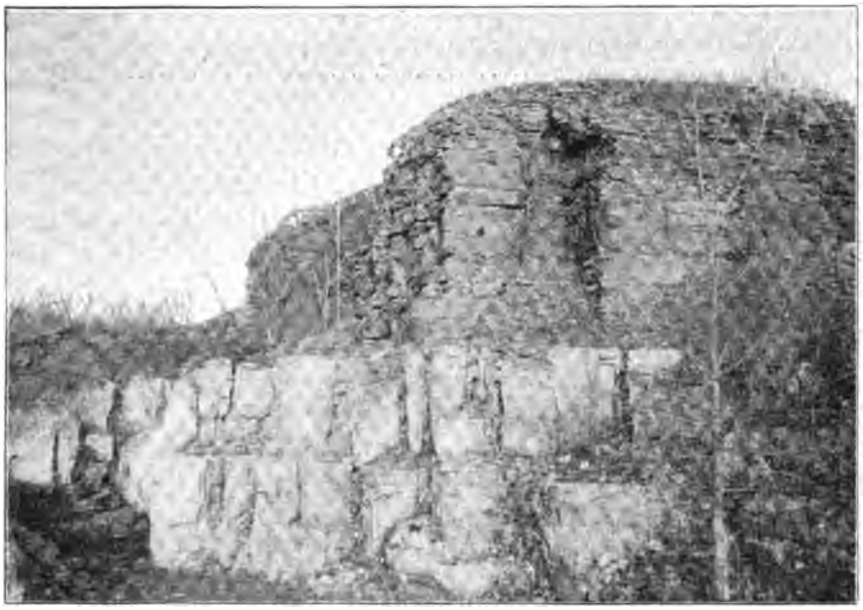

FIG. 29.—View in the Stevens' quarry in section 8, Indian Village township. The thin layers at the very top are limestone. The sand and impure limestone layers between contain numerous nodules of chert.

STEVENS QUARRY SECTION, BUTLERVILLE.

		FEET.
15.	Gray crinoidal limestone which weathers into thin pieces	1
14.	Crinoidal limestone, gray in color, with numerous fossil fragments	$\frac{3}{8}$
13.	Fissile limestone in thin layers, few fossils	4
12.	Brown magnesian limestone with layer of chert nodules two inches in thickness at the top	$\frac{3}{4}$
11.	Bed of rather soft, friable sandstone, much water seamed and containing numerous chert nodules, fossils few	7
10.	Arenaceo-magnesian limestone, fine-grained and quite hard, brown in color, layers 8 to 12 inches in thickness; containing casts of a species of Chonetes, Productus, Rhynchonella and Spirifer	4
9.	Bed of incoherent, brown, fine-grained sand	$1\frac{1}{6}$
8.	Band made up of chert nodules	$\frac{1}{3}$
7.	Impure arenaceo-magnesian limestone, few fossils	$1\frac{1}{12}$
6.	Bed composed largely of nodules of chert carrying a layer of sand, 3 inches in thickness	1
5.	Magnesian limestone containing some fine-grained yellow sand	$1\frac{3}{8}$
4.	Bed similar to number 5 above	$1\frac{1}{3}$
3.	Layer of massive oölite weathering into small bits and bearing numerous fossils among which appear *Orthothetes crenistra*, *Spirifer biplicatus*, *Spirifer cf. extenuatus* and *Straparollus latus*	7

		FEET.
2.	Layer similar to number 3 above in lithological characters and fossil contents	4½
1.	Layer of light gray oölite similar to numbers 2 and 3 above	3

The oölite rests on the argillaceous sandstone exposed in other sections in the vicinity and at the base of the northeast quarry at LeGrand. The beds here exposed correspond to the coarse-and fine-grained oölite and the magnesian limestone beds of the Marshall county sections.

West of Montour in the southwest corner of section 21, Indian Village township, there are exposed in a small ravine:

		FEET.
3.	Reddish brown clay, pebbly	4
2.	Oölite, light gray, fossiliferous	6
1.	Oölite, similar in every respect to number 2 above	3½

This is the abandoned quarry of the Oxford Lime Company. The oölite was formerly used in the manufacture of lime and considerable quantities were made at this place.

Other sections appear along the Iowa river toward LeGrand, and along Sugar creek in Carlton township and Deer creek in Spring Creek township. No new facies are presented.

WASHINGTON COUNTY.

The upper magnesian layers of the Kinderhook outcrop along South English river and its immediate tributaries, but they have little to commend them for structural purposes. They have been developed, however, to a limited extent near Riverside and Wassonville, and have been used for rough foundation work, well curbing and even for bridge stone, ordinary dimension stone and caps and sills. The stone is rather soft and not pleasing in appearance.

The Osage Limestone.

The Osage limestone occupies a triangular area in the southeastern portion of Iowa, the base of the triangle resting on the Mississippi river from Louisa to Lee counties, and the apex extending to the northwestward, reaching Keokuk county. Beds referred to this stage of the Lower Carboniferous are most extensively and typically developed in Des Moines county and especially in the vicinity of the town of Augusta. Five fairly well defined sub-stages may be recognized and as all are well represented in Des Moines county, their detailed descriptions appear in the discussion for that county and a repetition is unnecessary here. It may be said, however, that the indurated beds are chiefly limestones and that these supply the most important quarry rock in the southeastern portion of the state.

DES MOINES COUNTY.

Limestones and shales which have been referred to the Osage stage of the Lower Carboniferous immediately underlie the drift over by far the larger portion of the county. The limestones greatly predominate, although the shales become prominent near the top of the series.

For convenience of discussion the Osage, as developed in Des Moines county, may be divided into five fairly well defined members: the Lower and Upper Burlington limestone; the Montrose cherts; the Keokuk limestone, and the Keokuk and Warsaw shales.

The limestones are prevailingly pure, crinoidal and cherty throughout. The first and fourth members are heavy-bedded and coarse-textured, while the second and third are generally thinly, often irregularly bedded limestones.

The two divisions of the Burlington are the most conspicuous formations in the county, and form the steep bluffs which face the Mississippi, and its leading tributaries for a short distance above their debouchures, along the entire length of the county, and the Skunk river across the larger portion of the county's width.

The Lower Burlington occupies about fifty feet in vertical section, including about twenty feet of calcareous shales at the top. The limestone is coarse-grained, sub-crystalline, varying from pure white to brown or rusty in color, and occurs in rather heavy beds, especially near the base. Normally the rock is gray, the rusty brown being due to water staining. It is often quite cavernous. The upper shaly horizon carries much chert in concretions and bands and some calcareous ledges. The limestone is suitable for structural materials throughout, while the shale is practically worthless.

The Upper Burlington lies in thinner beds, and is more cherty and more shaly throughout than the lower member.

The most typical section of the Upper Burlington is shown in the Miller quarry, just above Cascade.

SECTION AT THE MILLER QUARRY.

		FEET.
8.	Loess	12
7.	Drift	3
6.	Limestone and chert	8
5.	Limestone, brown and white, banded with chert, thinly bedded	6
4.	Limestone, gray and white, heavily bedded	10
3.	Shale, blue, argillaceous, fossiliferous	2
2.	Limestone, heavily bedded, white	5
1.	Shale, blue, exposed	4

The majority of the quarries in the county are developing the Upper Burlington limestone. Quarries may be opened at almost any place in the faces of the bluffs fronting the larger streams, and excellent transportation facilities both by rail and water are often available. Some of the more representative quarry sections are appended herewith.

CITY QUARRY, NEAR MAIDEN LANE AND SEVENTH STREETS.

		FEET.
6.	Loess	12
5.	Drift	2
4.	Limestone, white, rather brittle, thinly bedded	3
3.	Limestone, yellowish, heavily bedded	5
2.	Limestone, poorly bedded, with considerable sandy clay and chert	2
1.	Limestone, white, solid bed	

The quarry supplies stone suitable for curbing and other dressed stone from numbers 1 and 3. The waste from these layers and from numbers 2 and 4 can be used for macadam and other crushed stone purposes.

Extensive quarries were operated by the government at Picnic Point about two miles south of Cascade. These quarries are now idle. The quarry section exposed is as follows:

PICNIC POINT QUARRY SECTION.

		FEET.
7.	Loess and drift up to	15
6.	Limestone, very cherty, brown, sub-crystalline, chert weathers yellowish	10

		FEET.
5.	Limestone, brown, encrinital, sub-crystalline, chert mainly in two zones; much weathered and cavernous in places	10
4.	Limestone, oölitic; somewhat shattered	1½
3.	Sandstone, argillaceous and calcareous, heavy-bedded when fresh; weathers decidedly shaly above; occasional large cherts in upper portion	5
2.	Limestone, concretionary zone, white and blue limestone, weathers yellow, and breaks up into thin, irregular layers	9
1.	Sandstone, argillaceous, white, washes on exposure, and apparently is pyritic; has a decidedly sulphurous odor, exposed	10

About one and one-half miles below the Government quarries, some quarrying is being done. Lime was burnt here and two kilns in a fair state of preservation still mark the site. The beds exposed are practically the same as these at the Picnic Point outcrop.

North of Burlington good outcrops are of somewhat less vertical extent, but equally numerous. In Flint River township a quarry on the northwest quarter of the southeast quarter of section 25 may be taken as a type and is given below:

LOFTUS QUARRY SECTION.

		FEET.
6.	Loess	4
5.	Drift	10
4.	Limestone, thinly bedded, with considerable chert	8
3.	Limestone, sub-crystalline, irregular, heavily bedded	10
2.	Limestone, white, solid bed	6
1.	Limestone, dark gray, somewhat irregularly bedded, exposed	4

All of the indurated rocks may be referred to the Upper Burlington. The beds may be viewed still farther to the northwest in Pleasant Grove township. In an old quarry on the northwest quarter of section 12, the following beds may be made out:

PLEASANT GROVE SECTION.

		FEET.
9.	Loess and drift	10
8.	Limestone, heavily bedded	6
7.	Limestone, rather brittle and poorly bedded	2
6.	Limestone, white, heavily bedded	6
5.	Shale, yellow, or calcareous sandstone	2
4.	Limestone, gray, irregularly bedded	4
3.	Chert	1
2.	Shale, or yellow sandstone, calcareous	2
1.	Limestone, thinly bedded	3

Stone is supplied to Pleasant Grove, Washington, and a large part of Yellow Springs and Franklin townships from these quarries. The stripping increases rapidly back from the face of the bluff, and quarrying has been and is carried on in a very desultory manner.

The Montrose cherts while present in numerous outcrops do not contribute materially to the natural wealth of the county. Commercially they are suitable only for crushed stone products. They are best exposed along the Skunk river. The chert beds rise to the north and only rather unimportant detached areas are known.

The Keokuk limestone occupies a broad belt across the southwest portion of Des Moines county, covering about one-fourth of its superficial area. This limestone is distinguished from the Burlington, lithologically, by its prevailingly blue color, less crystalline texture, and greater compactness.

The Keokuk limestone is a heavy-bedded, reasonably pure calcium carbonate well adapted for structural purposes. It is less quarried than the Burlington, on account of greater overburden and poor transportation facilities.

A representative section may be viewed in the vicinity of Augusta, where both the Montrose cherts and Keokuk beds are well shown. The sequence is as follows:

AUGUSTA SECTION.

		FEET.
4.	Drift	8
3.	Limestone, bluish, encrinital in places, clay partings, often highly fossiliferous (Keokuk)	20
2.	Chert, white, thinly bedded, with thin irregular bands of limestone (Montrose)	30
1.	Limestone, white, coarse-grained, encrinital (Upper Burlington), exposed	15

Farther up the Skunk river the Saint Louis limestone and Coal Measures come in, and the Keokuk beds dip below the level of the stream. Small quarries have been worked from time to time in Danville and Union townships, but these were of local interest only. In many of the outcrops, cherty material is so abundant that the stone is practically worthless save for crushed stone purposes.

KEOKUK COUNTY.

The Osage limestone is believed to occupy a triangular area in the northeast corner of the county and several patches are known to occur in the interior of the county. The most important outcrops may be seen along Rock creek and Skunk river north to northwest of Ollie. The formation rises forty feet above the river. The stone varies from light brown or white to gray in color. It is medium to coarse-grained, sub-crystalline and lies in ledges usually three to ten inches in thickness, separated by clay and chert bands. It is highly fossiliferous, oftentimes consisting largely of a shell breccia and fragments of crinoid stems. The most extensive section occurs in the vicinity of Manhattan Mills. The following sequence was determined by Bain:

		FEET.
7.	Soil and drift of indefinite thickness	2–40
6.	Sandstone, quartzose, in part calcareous, soft, yellow	1½
5.	Limestone, finely brecciated	1
4.	Limestone, compact, gray, cherty	20
3.	Limestone, earthy, brown, containing numerous chert nodules	15
2.	Limestone, coarse sub-crystalline, blue and gray in color, fossiliferous, in ledges 9 to 20 inches thick, separated by shales 6 to 8 inches in thickness; bands of chert nodules 3 to 10 inches thick near the top	26
1.	Limestone, as above	14

Numbers 1 and 2 in the above section belong to the Osage, the first being exposed in the Weber quarry near the mill, while number 2 comprises the chief formation in the Cook quarry. Number 3 is referred to the Springvale beds, and outcrops above the quarry tracks, while numbers 4 to 6 inclusive belong to the Verdi beds of the St. Louis stage and are exposed along the old right of way leading to the Cook quarry.

The railway switch has long since been abandoned and the steel removed. Quarrying is carried on only to supply the local demand. In a local quarry still in operation, the following beds are displayed:

		FEET.
4.	Loess, waste and drift	1–5
3.	Limestone ledge, similar to number 1	1¼
2.	Limestone, thinly bedded, concretionary and cherty; shaly	3
1.	Limestone, blue-gray, evenly bedded, about five ledges exposed, varying from 6 to 12 inches in thickness; sometimes there is a shaly parting near the middle; fossiliferous	3

Numbers 1 and 3 afford a good quality of stone for coursing and rubble work. The several other exposures of Osage limestone present no new features.

LEE COUNTY.

The Osage limestone comprises a very considerable portion of the country rocks in Lee county and forms the greater part of the vertical extent of the bluffs on all of the streams bordering the county. In the interior it is largely overlain by the Saint Louis and the Coal Measures.

It includes quite a diversity of beds which for convenience in discussion are divided into three groups of limestones which are separated by shales and chert beds. The lowest member is generally known as the Burlington, which many investigators have divided into Upper and Lower Burlington. This is separated by chert beds from the middle member, the Keokuk limestone, which in turn is separated by shales and geode beds from the uppermost member, known as the Warsaw.

The Lower Burlington, while composed in part of heavy beds of sub-crystalline limestone, is unimportant in the present connection as it comprises only a narrow strip along the base of the Skunk river bluffs north of Wever and a few miles east of the town of Augusta in the northeastern part of the county.

The Upper Burlington is very similar in character to the Lower Burlington, but usually occurs in thinner beds and carries a greater abundance of chert in irregular nodules and thin bands. The Upper beds are best exposed in the bed of Skunk river at Augusta. The flinty beds of the Upper Burlington are sometimes called the Montrose cherts. They appear along the Mississippi river from Montrose to Keokuk. Between these points they constitute the bed of the river and cause the obstruction to navigation known as the Des Moines rapids. While both members of the Burlington afford good material for constructional purposes, neither is sufficiently accessible to merit extended notice.

A quarry has been opened in the Burlington limestone, west of Wever. The beds worked are as follows:

		FEET.
5.	Soil and drift	4
4.	Limestone, brownish, thinly bedded, with some chert, encrinital	1½
3.	Limestone, white, rather soft, somewhat cherty in places	½
2.	Limestone, yellowish	2½
1.	Limestone, hard, brown, encrinital, heavily bedded, exposed	2

Other openings have been made in the near vicinity but while the stone is durable and pleasing in appearance, the aggregate annual output has never been large and is practically *nil* at this time.

The Keokuk beds are typically developed in Lee county, but at the same time their surface area is relatively small. These beds occupy the larger portion of Denmark township and a part of Washington. In addition thin beds are exposed in the bluffs facing all of the larger streams. Along the Des Moines river, while the Keokuk is present above the water-line, it is largely obscured by heavy talus slopes. In general the formation consists of twenty-five to forty feet of coarse-grained, bluish, often crinoidal limestone, overlain by rather more than thirty feet of shales, generally known as the geode beds. Chert is quite prevalent through the limestone, while some beds are somewhat argillaceous and from these two causes, many of the layers are unfit for dimension stone, but are serviceable for crushed stone purposes. The best layers for dimension stone are known as the "White ledge" which is quarried in Keokuk and vicinity. The heaviest beds and thinnest partings are near the base, while the beds become thinner and more argillaceous in character near the top, grading into the geode beds above.

The geode beds are of small importance in the discussion of "quarry products" save as a possible source of shales suitable for use in the manufacture of Portland cement. The lower half is made up largely of more or less indurated calcareous shales with some chert and occasional bands of limestone, graduating downward into the limestone below. The upper half is more argillaceous, sometimes slightly arenaceous and less calcareous and slakes more readily under weathering influence than the lower portion. The siliceous and calcareous concretions give name to the formations and are quite generally, although not universally, present in southeastern Iowa.

The Keokuk limestone has always been a large contributor to the stone output of the county. Numerous quarries have been opened, and it is this horizon which affords the greater portion of the quarry rock in the vicinity of the city of Keokuk. As a rule the formation is compact, rather hard, often sub-crystalline rock, of an ashen or bluish gray color. It presents an even to conchoidal fracture.

The Warsaw beds comprise a buff magnesian limestone at the base, in a massive layer often ten to twelve feet in thickness; blue arenaceous shales with intercalated limestones in thin bands, and at the top a buff, sandy limestone locally called "sandstone." These beds are typically developed at Warsaw, a town five miles below Keokuk on the Illinois side of the river.

The quarry rock of the Warsaw is chiefly a magnesian limestone containing some sand and small pebbles. It is generally called sandstone. The principal quarries are located at Sonora on the east side of the river. The rock occurs in a massive layer ranging from six to twelve feet in thickness, is bluish to yellowish in color when first taken out of the quarry, but, on exposure to the weather for some time, it changes to a buff or brown. The stone has been used in the building of the locks and many of the most important structures in the city of Keokuk. It has also been used in pier and bridge work. It is very durable and highly prized for all grades of dimension and cut stone work. The principal quarries in the county are located near the city of Keokuk, within half a mile of the railway bridge crossing the Des Moines river, and near Ballinger, above the city along the Mississippi river.

Of the numerous sections of Osage available, only sufficient are selected to illustrate the principal features of the beds. There is an almost continuous outcrop of these beds in and about the city of Keokuk and facing the principal streams on the three sides of the county.

The Tigue quarry, a short distance west of the Rand lumber yard, is one of the oldest openings in the vicinity. It has been in operation for more than forty years. The section is as follows:

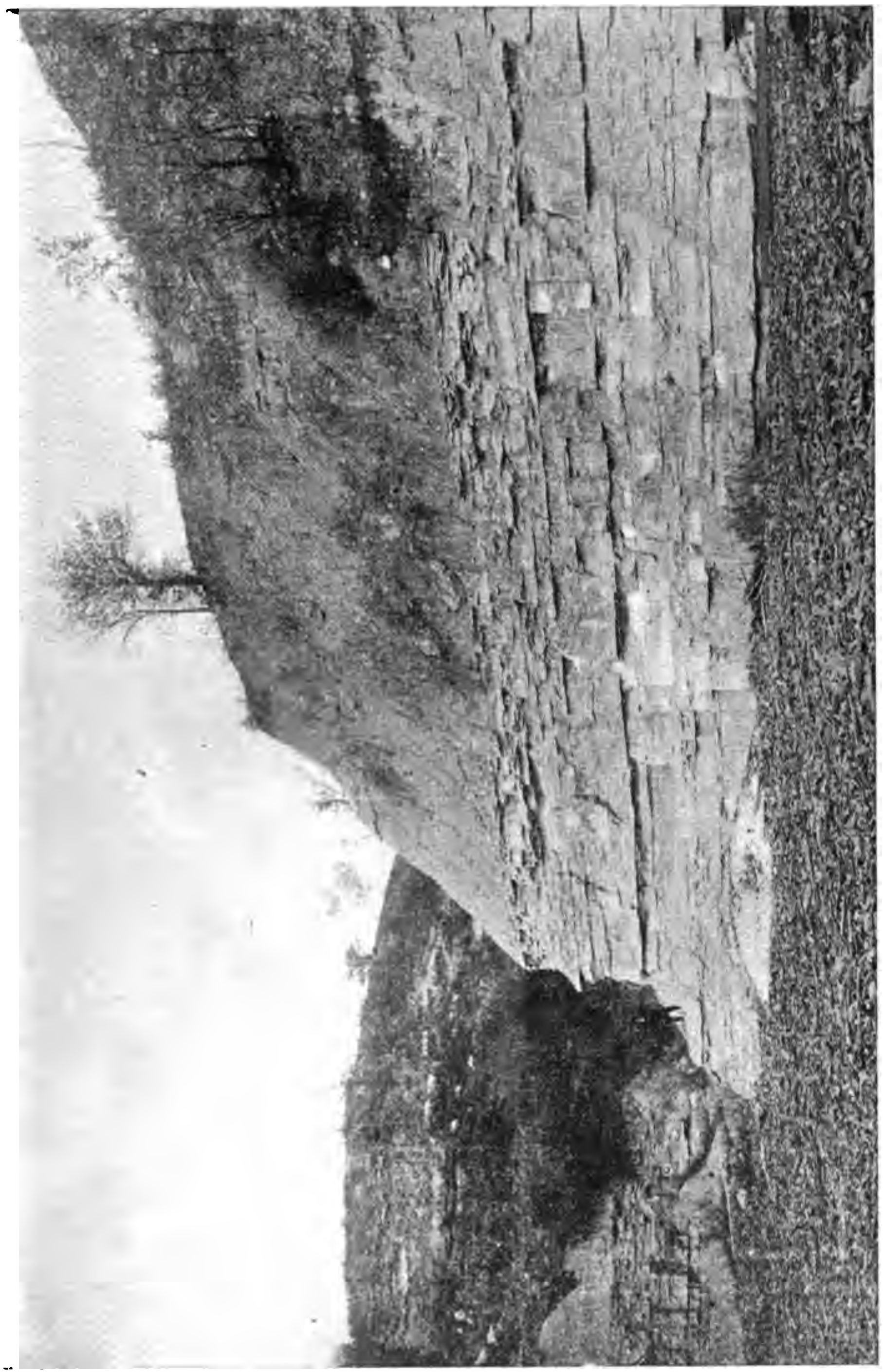

PLATE LIV—Quarry at McGavic mill, Keokuk.

		FEET.
4.	Soil and drift	8
3.	Limestone, thinly bedded, with considerable calcareous shale	6
2.	Limestone, more massive than 3	9
1.	Limestone, rather sandy, with shaly partings, exposed to railway track	14

In the west part of the city of Keokuk, along Soap creek for a distance of fully one mile, quarries have been opened at a number of points. The section exposed near the mouth of Soap creek is given below:

		FEET.
8.	Soil and drift of variable thickness.	
7.	Shale, cherty	6
6.	Shale, calcareous, with intercalated beds of limestone; some geodes present	8
5.	Limestone, drab, impure, heavily bedded, shaly below	12
4.	Limestone, light colored, with nodular masses of chert; the "white ledge"	3
3.	Limestone, argillaceous and massive, with spheroidal masses of calcite, sometimes carrying millerite	5–6
2.	Limestone, coarse, gray, encrinital, cherty	3
1.	Limestone, with chert in irregular beds, exposed	5

North of the city about one-fourth mile north of Ballinger station on the C. B. and Q. Railway, the Tucker and McManus quarry displays the following beds:

		FEET.
7.	Soil, loess and drift	0–10
6.	Limestone, weathered, soft, yellowish above, blue-gray below; yields some rubble where protected; somewhat cherty	10–15
5.	Limestone, shaly	1
4.	Limestone in two heavy beds, the upper about three and the lower three and one-half feet in thickness, separated by a one foot shaly parting; fossiliferous and sub-crystalline	7½
3.	Limestone, cherty, sub-crystalline, similar to 1, somewhat irregularly bedded; where sufficiently free from chert yields good rubble stone	8
2.	Limestone, evenly bedded, gray-blue, sub-crystalline	1½
1.	Limestone, chert present as bands and nodules, irregularly distributed throughout, exposed	6

In this quarry the beds dip to the northwest. Numbers 2 and 4 furnish the best dimension stone. Only hand methods are used in quarrying, although a steam drill is employed. Power for drilling is supplied by an ordinary traction engine. The waste stone is loaded in cars with removable beds. The car beds are swung up to a Gates crusher by means of the only derrick used in the plant. All of the stone below the weathered zones is utilized. The crushed stone is graded by being passed through a cylindrical screen. Storage bins are provided for the larger sizes. The dust is removed by a belt conveyer and dumped on the ground. In addition to crushed stone, rubble and dimension stone are produced. This is the most important quarry in the county at this time.

LOUISA COUNTY.

The underlying, indurated rocks that are exposed in Louisa county belong almost exclusively to the Kinderhook and Osage stages of the Mississippian. The Kinderhook beds consist chiefly of soft clays and impure limestones, with occasional strata of sandstone. The Osage is represented by the heavier, more durable beds of the Burlington limestone. Exposures are found in the southern and southwestern portions of the county. They appear to best advantage in the bluffs west of the Mississippi and south of the Iowa river in Elliott, Wapello and Morning Sun townships. Outcrops are also common along the streams in Columbus and Elm Grove townships.

The best stone comes from the Upper Burlington beds and all of the present working quarries make use of these strata. The lower beds were formerly worked on the property of J. D. Anderson, just south of Elrick Junction, but this rock is usually too much weathered to furnish durable building material. The principal quarries are located near Morning Sun on Honey creek and on Long creek and its tributaries.

The Chas. B. Wilson quarry, one and one-half miles east of Morning Sun in the southwest quarter of section 28, affords a characteristic section of the Upper Burlington. The following details are based in part on data found in the *Geology of Louisa County.**

		FEET.
6.	Disintegrated crinoidal limestone, brown to yellow...........	3½
5.	Partially weathered crinoidal limestone containing some chert; ledges 4 to 6 inches thick, fair stone........................	2¾
4.	White chert, nearly fails in places...........................	½

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*J. A. Udden, Iowa Geol. Survey, Vol. XI, p. 76.

	FEET.
3. Yellowish fine-grained limestone, containing open pockets often lined with botryoidal calcite or quartz crystals, soft and can usually be crumbled to a powder in the fingers....	1-3
1. Coarsely crystalline pure limestone, light brown to bluish white; in ledges from one foot above to massive three-foot ledges below; stylolitic jointing very common; free from chert..	6

The quarry base is about twenty-five feet above low water in Honey creek. This depth consists largely of cherty limestone in part obscured. A face approximately one-fourth mile in length has been opened on both sides of the stream and a large amount of stone removed. With the exception of the upper few feet, there is little worthless material in the section, and numbers 1 and 3 especially afford a most excellent stone for any of the finer grades of work. A considerable acreage is available at this point, both to the east and west of Honey creek, over which there is no drift and little else to require much dead work in stripping.

A similar succession is found at the W. C. Bryant quarry just south of the Iowa Central track in the southeast corner of section 29. Seven and one-half feet of number 1 are quarried, and the opening has reached such a depth that number 2 is quite firm and unweathered. It is seen to be a coarsely granular and fossiliferous brown limestone similar to number 3, save for the presence of numerous geode cavities. The heavy beds furnish suitable stone for heavy foundations, bridge piers, and other masonry work, besides walls and finishings. The white stone does not, however, split with uniformity in any direction except along well defined lines of stratification.

The stone is handled in this quarry by derrick to wagons and some is shipped from Morning Sun.

Number 1 in these quarries is an unusually pure limestone as shown by the chemical analysis, given herewith, of a sample from the Wilson property.

Insoluble..	1.60
Iron oxide and alumina ($Fe_2O_3 + Al_2O_3$)......................	1.20
Lime carbonate ($CaCO_3$)	97.02
Magnesium carbonate ($MgCO_3$)................................	.32
Hygroscopic moisture..	.34
Total...	100.48

The very low magnesia content commends the stone for the manufacture of Portland cement. It would also make, without doubt, an excellent grade of white lime.

Both the Wilson and the Bryant quarries are conveniently located for transportation of the output by rail. The stone is of high quality and limitless quantities are available. The territory to be supplied is principally the counties to the westward of Louisa which are heavily drift laden and possess no building stones of their own.

The Ackenbaum quarry is located in the northwest quarter of section 27, Morning Sun township. The beds here consist of about three feet of overlying disintegrated crinoidal limestone, associated with the lighter colored heavier beds as exposed on Honey creek. The latter are beds coarsely crystalline to saccharoidal in texture. A stylolitic structure is common but the rock splits irregularly and with no greater facility along such lines of jointing. The stone outcrops for some distance along Gospel run and at the quarry face is covered with but one to three feet of loess-like soil. Immediately back from the streams, however, there is a heavy drift covering.

There are a number of small quarries situated along Long and Buffington creeks in Columbus and Elm Grove townships respectively. The old Wasson, now C. J. Gipple, quarry, in the low terrace along the south bank of the south branch of Long creek in the northwest corner of section 23, Elm Grove, affords the following section:

		FEET.
9.	Soil in small amount which does not thicken materially for several rods from quarry face.	
8.	Limestone, badly shattered, containing much chert below ...	7
7.	Disintegrated limestone carrying much chert. Worked back in the hill, becomes a fairly firm rock of bluish color and crystalline texture; separates into ledges of 6 inches to 1 foot..	
6.	Yellow, disintegrated limestone, in part solid and coarsely crystalline..	3
5.	Blue shale, calcareous....................................	1
4.	Band of chert, fossiliferous, persistent, used for building rock. A maximum of..	1
3.	Yellow, badly disintegrated crinoidal limestone with geode cavities, in part a crumbling brown sand.................	4
2.	Yellowish, partially disintegrated but usable limestone.......	1½
1.	Crinoidal white limestone, in ledges from 6 to 10 inches.	

No. 1 is not now in sight but has been taken out to a depth of twelve feet as the principal quarry rock. The base of the full quarry face would therefore, be somewhat below water level in the creek.

These same beds crop at an indefinite number of points in this vicinity on Long creek and in section 14 of Elm Grove township on Buffington creek.

J. L. Thurston takes out a small amount of stone near the northwest corner of section 14, and J. E. Gray and J. M. Marshall quarry the same "white" beds in the north part of section 3, Columbus township. At the Marshall quarry, considerable stone has been quarried in the past and there is less stripping needed than at other observed points where quarrying is done.

Western Louisa county in general, is heavily drift laden and the rocks are exposed only at infrequent intervals along the streams.

VAN BUREN COUNTY.

Both the Upper and Lower Carboniferous series are represented in the rocks of Van Buren county; the former by the Lower Coal Measures or the Des Moines stage and the latter by the limestones of the Saint Louis, the shales and limestones of the Keokuk and the Montrose cherts of the Burlington sub-stage. Exposures occur chiefly along the Des Moines river and its tributaries, although a few outcrops of the Saint Louis are to be seen along Cedar creek and branches, near the northeast corner of the county.

The beds belonging to the several stages and formations bear the customary relations to each other. Between the Des Moines and the Saint Louis is a major unconformity and evidences are to be observed of a break in sedimentation between the Saint Louis and the Keokuk beds. A marked anticlinal with its crest at Bentonsport brings the Burlington cherts into view in the channel of the Des Moines river between Bentonsport and Bonaparte. A maximum of forty feet of these beds is exposed, but they disappear both to the north and south within narrow limits. The Burlington consists of beds of chert with occasional bands of limestone or calcareous shale but affords in this county no quarry products.

Keokuk beds:—This member is exposed along the Des Moines from the mouth of Rock creek in Washington township to the southeast corner of the county. It is found exposed in only a narrow belt along the river, where it is usually overlain by the limestones of the Saint Louis. The formations belonging to the Keokuk sub-stage in Van Buren county consist of the Keokuk limestone below, the Geode shales and, at the top, the Warsaw shales. C. H. Gordon writes as follows regarding the Keokuk limestone, its distribution and character:

"The Keokuk limestone makes its first appearance in the extreme southeastern part of the county on a small branch on the south side of the river. About six or eight feet are exposed, and quarried to a limited extent. The next appearance is at the mouth of Reed creek, where about ten feet of bluish gray limestone, coarse, sub-crystalline and mostly thin-bedded, are exposed. As the strata rise toward the west, lower beds come into view, and are seen well up in the bluff below Bonaparte, with nearly thirty feet of the Burlington chert beds below. The lime-

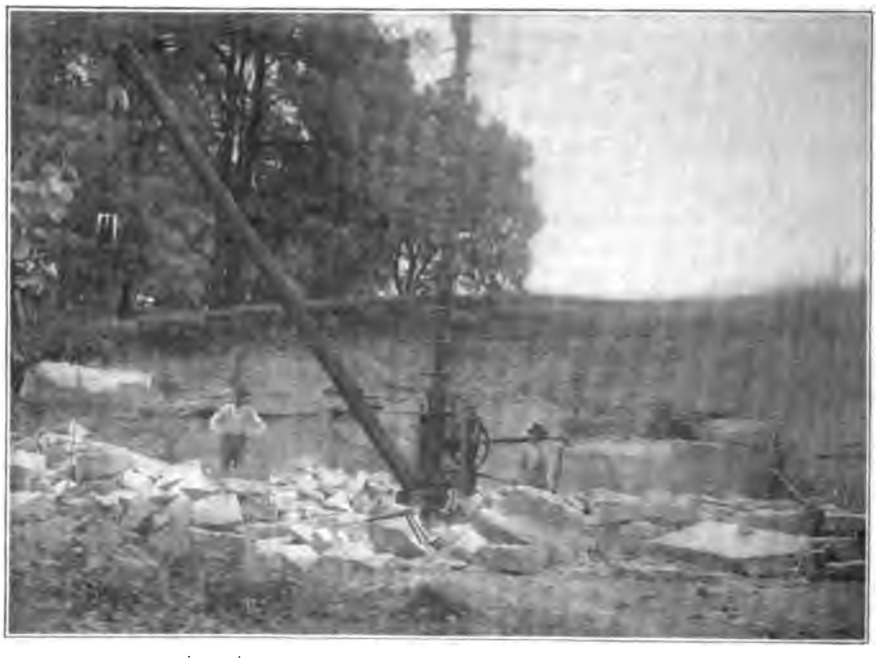

FIG. 30—Davis quarry, west of Bentonsport, Van Buren county. Heavy beds of magnesian sandstone (Warsaw Sandstone).

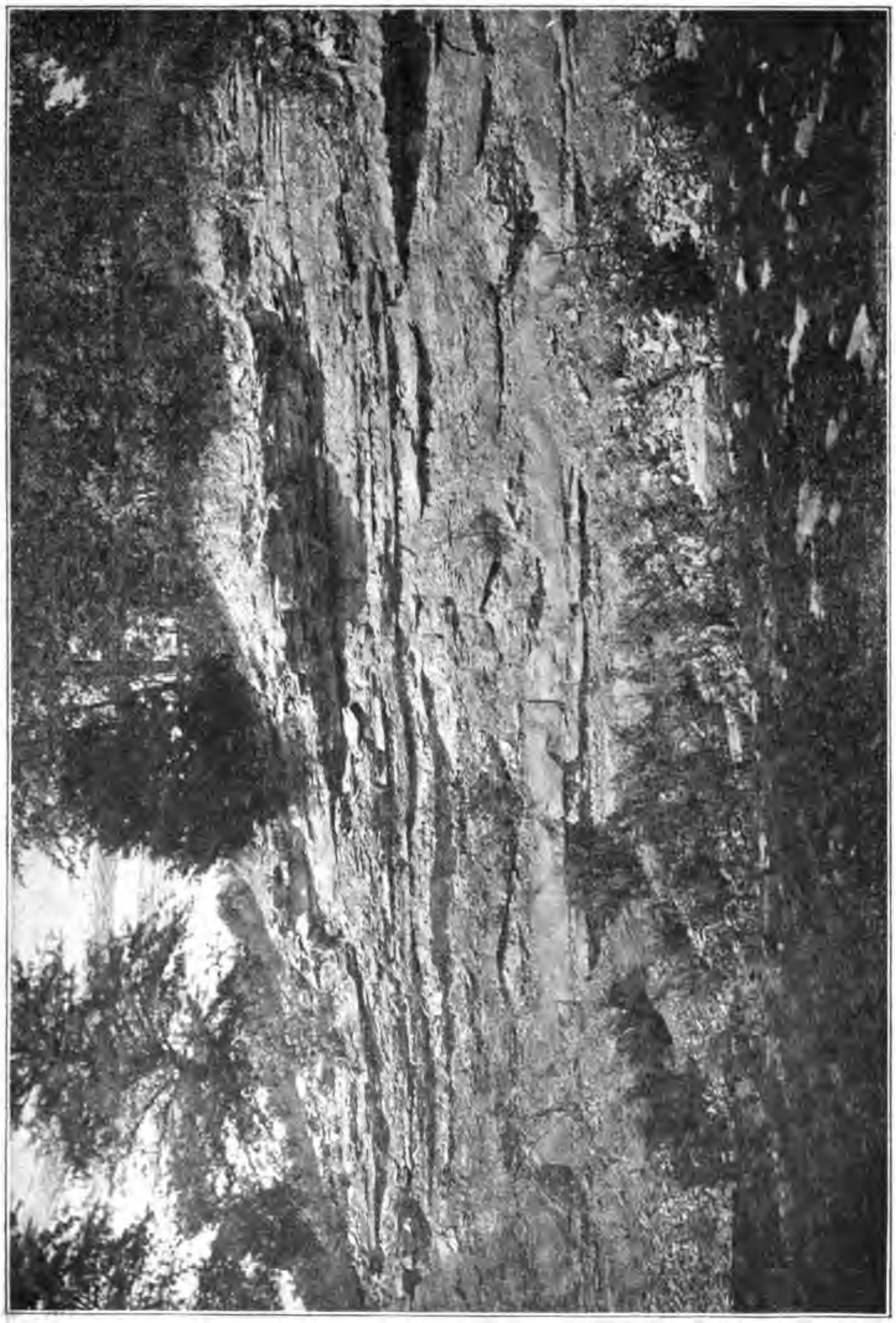

PLATE LV—Old quarry opening in Bentonsport, Van Buren county, Iowa.

stone has been quarried at several places here, but it contains large quantities of chert. Much of the rock is also shaly and the bedding of the better quality of rock is quite variable. At Bentonsport at one time, quarrying was carried on quite extensively. The principal quarry bed is from five to eight feet above the base of the division and perhaps represents the same ledge as that quarried at Keokuk and there termed the "white ledge". The upper layers at the quarry are thinner. The horizon between the thicker and thinner beds is marked by a series of undulations of one of the beds remarkable for their regularity. The vertical interval of the unduations does not exceed ten inches, while the horizontal interval does not vary much from fifteen feet throughout the whole extent of the quarry. On the opposite side of the river the rocks are well exposed for some distance up Bear creek, and show essentially the same characters as elsewhere in southeastern Iowa."*

The limestone has been quarried at a number of points in the vicinity of both Bonaparte and Bentonsport but most extensively at the latter place, where the following is the approximate section:

		FEET.
7.	Geode shales, at quarry face	10+
6.	Argillaceous limestone, carrying much chert and some geodes	2
5.	Blue-gray limestone in thin ledges with interbanded black shale and numerous chert bands	8
4.	Persistent bed, blue, crystalline, fossiliferous limestone with usually a band of chert	1⅙
3.	Calcareous, dark gray shale	1
2.	Heavy bed, clean, blue-gray, coarsely crystalline	1⅓
1.	Calcareous shale.	

The quarry face is intermittently open in the bluff above the town for one-fourth of a mile. The base of the quarry is about forty feet above water in the river and twenty feet higher than the railway track which runs at the foot of the bluffs. Numbers 2 and 4 only have been used, and these have furnished stone for bridge piers and riprap. The stone has not proved very durable in exposed positions. It is believed, however, that all the beds might be used for crushed stone and the situation is suitable for such an industry. The exposures are in general covered with the geode shales and heavy drift.

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*Geology of Van Buren County, Iowa Geological Survey, Vol. IV, p. 211.

Equivalent beds have been worked by the Chicago, Rock Island and Pacific Railway Company, three-fourths of a mile east of the town, but they are no longer used.

In the vicinity of Bonaparte the Keokuk limestone is occasionally quarried for local use. The following layers are to be seen in the southeast quarter of the southwest quarter of section 9, Bonaparte township:

	FEET.
3. Drift	3-10
2. Limestone, blue, irregular, thin-bedded; intermixed with layers of shale; fossiliferous, cherty	7½
1. Limestone, blue, hard, cherty, thick-bedded, main quarry rock; exposed	6

Farther up Mack creek the fine-grained yellow limestone appears and has been quarried at a few points.

WASHINGTON COUNTY.

Limestone beds referable to the Osage outcrop at numerous points in a belt which crosses the middle portion of the county in an east and west direction. Quarries have been opened northwest of Washington and north of Wellman. The Eckels quarry, located on the southwest quarter of section 2, township 75 north, range VIII west, presents one of the best sections between Washington and West Chester and is given below.

ECKELS QUARRY.

	FEET.
3. Loess	12
2. Drift	6
1. Limestone, coarsely sub-crystalline, blue, gray and white in color, running in ledges from 3 to 20 inches in thickness	20

Other quarries in the neighborhood display less extensive sections and present no new features of importance. Chert bands are quite common in all of the quarries and in one of the quarries an earthy to arenaceous bed carrying calcareous geodes may be viewed. North of Wellman, near Dayton, an old quarry shows the following indurated beds:

	FEET.
3. Limestone, buff, arenaceous	5
2. Limestone, brown, coarse, sub-crystalline, fossiliferous	½
1. Limestone, blue to gray, finely sub-crystalline, fossiliferous	4

The stone very closely resembles that quarried in the Washington district. Openings have been made at other points, but are of local interest only.

The Saint Louis.

The Saint Louis stage of the Lower Carboniferous has been separated by Bain into three sub-stages. The lowest of these, the Springvale beds, comprises a limestone formation varying from earthy or argillaceous limestones as developed in Keokuk county at the type locality to massive limestone beds in Henry county. As a rule the beds are not important as a source of quarry products. The middle member, or Verdi beds, is exceedingly variable in composition and texture, ranging from sandstones to shales or limestones. The different kinds of sediments give place one to another, horizontally, so that a stratum that is shale in one part of the exposure may be represented by sandstone or limestone at no great distance to the right or left. No important quarries belong to this horizon. The uppermost member, or Pella beds, is the most uniform in character and is fairly persistent over considerable areas. The beds are usually quite pure limestones, are of good thickness and evenly bedded. The Pella beds comprise the most important member of the Saint Louis stage from an economic standpoint.

DES MOINES COUNTY.

The Saint Louis limestone covers a small area in the southwest corner of the county. The principal outcrops occur in the valleys of Long and Cedar creeks and the Skunk river. The beds comprise, in descending order, a white clay marl; gray flag-like limestone; brown, arenaceous limestone; and a concretionary and brecciated limestone.

The gray, coarse-grained limestone is regularly bedded, and occurs in thin, flag-like layers from two to five inches in thickness. It is quite compact and outcrops on Long and Cedar creeks north of Augusta, where some quarrying has been done.

The brecciated limestone is a very fine-grained, compact limestone, light blue or ash-gray in color, and breaks with a well marked conchoidal fracture. The fragments are all more or less angular and vary in size from microscopic particles to blocks several feet in length. They are firmly embedded in a matrix of a hard, greenish, calcareous clayey material which weathers more readily than the limestone fragments. As far as known the flagstone member of the Saint Louis is the only one which has been quarried and the beds as a whole are much less important from an economic standpoint than their equivalents in Lee county.

LIME.

All of the major divisions of the Lower Carboniferous rocks developed in the county contain beds suitable for the manufacture of lime. This is especially true of the Osage stage. Lime has been manufactured at a number of points, notably in the vicinity of Burlington, Augusta and along Flint river. Two kilns, in a fair state of preservation, still stand near Patterson. No lime was produced during the past year.

HAMILTON COUNTY.

The Saint Louis limestone comprises the only available beds in the county which are sufficiently indurated to be used for structural purposes. On account of the distribution of the Coal Measures over almost the entire county and the great thickness of the drift, exposures are limited to the immediate vicinity of Boone river from a short distance above Webster City to section 31 in Independence township. Along a small creek which flows into the Boone river just below the mill in Webster City, a quarry has been opened and operated more or less continuously for a number of years. The section which can be made out is as follows:

SWANSON QUARRY.

		FEET.
5.	Loam and drift	2+
4.	Sandstone, clayey, fissile, ash-gray in color	2
3.	Limestone, impure, thinly bedded, much weathered, in places altered to a calcareous, arenaceous clay	4
2.	Limestone in fairly heavy beds, with occasional quartz geodes	4-5+
1.	Sandstone, light colored, somewhat friable but in places hard enough to be used for structural purposes, exposed	4

Number 2 constitutes the principal quarry rock, and was formerly much used locally, and is practically the only native stone available for structural purposes. It is a fairly pure limestone, of fine, even texture, varying from a gray to a yellowish buff. It shatters when subjected to changes of temperature when wet, but gives good service when put in the wall dry. The upper members exposed are rather inconstant and in places are absent, the drift here resting directly on number 2.

While similar sections are exposed both up and down the river from the Swanson quarry, the excessive overburden, the small thickness and the indifferent quality of the beds make quarrying on a commercial scale impossible.

The phase of the Saint Louis exposed in Hamilton county closely resembles its development in Story county and probably represents the Verdi sub-stage, which is typically exposed from Marion to Washington counties.

HENRY COUNTY.

The various sub-stages of the Saint Louis limestone immediately underlie the glacial debris over practically the entire county. The Coal Measures fringe the south and west borders more or less interruptedly, with small patches in the interior, and two narrow bands of the Osage limestone are exposed along the Skunk river in the south central and southeast portions of the county.

The lowest member, or Springvale sub-stage, is dolomitic in character, occurs in heavy beds, and affords material suitable for heavy masonry. The best sections occur in Baltimore township, and to a less extent in Jackson and Center townships. As a rule, the beds suitable for structural purposes are under a heavy overburden and can be quarried only at great expense. The following sections will serve as fair examples.

Section about one mile east of Lowell, in Baltimore township, north of wagon road:

		FEET.
7.	Clay, reddish colored and gravelly	6
6.	Limestone, impure, rusty brown	2
5.	Limestone, brown, magnesian, similar to 4	4
4.	Limestone, magnesian, obscurely laminated	3½
3.	Limestone, brown, magnesian, in layers three to seven inches thick	8
2.	Limestone, fine-grained, magnesian, brown, in layers one to three feet thick	10
1.	Limestone, variable, partially concealed down to geode beds of Keokuk sub-stage	9

The heavy dolomitic beds would undoubtedly give good service for heavy masonry, but have been but little developed and are not readily accessible.

The middle member of the Saint Louis, the Verdi, as developed in the county, is characteristically variable in composition, texture and structure, and has little to commend it commercially save for crushed stone purposes. It has not up to this time been exploited on its own account. It has been worked only to a limited extent in connection with the beds above and below.

The uppermost member, or Pella beds, is the most widely distributed and most generally accessible of any of the divisions of the Saint Louis and has been more extensively developed than any other formation in the county. While the quarrying industry amounts to but little at the present time, large quantities of stone have been produced by the quarries near Mt. Pleasant, along the Keokuk and Western division of the Chicago, Burlington and Quincy Railway. The old Winter quarry, located in the south bank of a small stream emptying into Big creek from the north, near the railroad bridge in the southeast quarter of section 17, Center township, shows the following section:

		FEET.
12.	Drift, reddish brown	4
11.	Limestone, gray, weathered, shaly	6
10.	Limestone, light gray, compact, layers ten to twenty inches in thickness	5
9.	Limestone, gray, evenly bedded, in layers two to eight inches in thickness	6
8.	Limestone, gray, flaggy, two to four inches in thickness	1
7.	Limestone, fine-grained, in undulating layers one to three feet thick	8
6.	Limestone, fine-grained, gray, brecciated, in places much shattered	5
5.	Sandstone and shales in lentils and irregular beds	6
4.	Limestone, light colored, arenaceous, in places flexed and often brecciated	6
3.	Chert in a band rather than in nodules	1½
2.	Limestone, impure, yellowish; the upper portion in thin layers, the lower a single bed three feet in thickness	4
1.	Laminated beds, one to three inches in thickness, consisting of brown, magnesian layers above, thin layers of oölitic limestone in central portion and arenaceous magnesian limestone below	5

The upper surface of number 1 presents numerous dome-shaped elevations ranging from two to four feet in height and ten to twenty feet in diameter. Both 1 and 2 show well defined ripple marks in places.

The Pella beds are exposed at numerous other points, but on a less extensive scale than in the above section, and do not present any new features worthy of mention. While quarries have been opened and operated from time to time in practically every township in the county, those in the vicinity of Lowell, Salem, Oakland Mills, and Mt. Pleasant are the most important.

LIME.

All of the limestone when burned yields a usable grade of lime. In the early history of the country, sufficient lime was produced to supply local consumption. In recent years, however, the increased cost of wood fuel, the modern plants at other places, combined with cheap freight rates, have conspired effectively to put an end to the local industry.

HUMBOLDT COUNTY.

The Saint Louis limestone appears at several points along both branches of the Des Moines river and in Weaver township. It forms a solid foundation for a large portion of the city of Humboldt, as the cellars of many of the principal buildings were excavated in it, and, it is said, produced enough stone to build their own walls. The stripping or overburden of soil and drift is so thin in places that these limestone beds afford a natural pavement. The Saint Louis overlies the Kinderhook unconformably, although good natural exposures showing the contact are scarce. The most extensive section in the county appears along the east bank of the river, near the south line of the county. The beds are as follows:

		FEET.
9.	Drift of variable thickness.	
8.	Sandstone, probably Coal Measures	6- 7
7.	Limestone, in thin layers, arenaceous	6-10
6.	Limestone, heavy-bedded, containing angular fragments of lithographic stone	5- 7
5.	Shale, with pockets of clay; variable in thickness; a thin parting	1
4.	Limestone, hard and dense	4

		FEET.
3.	Limestone, regularly bedded, more or less arenaceous, about	2
2.	Talus to water level	4
1.	Limestone, soft, whitish or bluish in the bed of the river. On exposure turns brown or yellow and washes readily under rain. Occurs in layers six to eight inches thick, and is said to overlie blue shales.	

Number 1 has been quarried in the bed of the river for local use. Number 7 is the most characteristic and clearly defined member of the series. It occurs in layers three to four feet thick, is unevenly bedded, more or less brecciated and breaks off in large blocks as undermined by erosion of the thinner beds below. This particular horizon also outcrops in sections 31 and 32 in Grove township.

The Bull quarry near the center of Humboldt exposed the following section:

		FEET.
3.	Drift and soil	1-2
2.	Limestone, thin-bedded, with flinty layers, passing into beds of clay	2
1.	Limestone, blue, evenly bedded, of variable texture	6

Number 1 rests unconformably upon the subjacent limestone, which is supposed to belong to the Kinderhook. Other exposures of the Saint Louis limestone occur at the "Sandstone Quarry" in Rutland, and at several points in Avery and Weaver townships. The best beds usually available at all of these places, occur in medium to heavy ledges, are comparatively pure calcium carbonate, and yield a fair to superior grade of building stone, which has been used extensively in bridge piers and abutments, foundations and walls of some of the best buildings in the county.

JEFFERSON COUNTY.

Jefferson county belongs to the region of thick drift, which, according to Udden, averages one hundred and fifteen feet in thickness over the entire county. Both the drift and the Coal Measures have been completely removed by the principal streams in Penn, Walnut and Lockridge townships in the northeast, and to a less extent in Round Prairie, Cedar and Liberty townships bordering on the south line of the county. Numerous outcrops of Saint Louis limestone appear in all of these townships. As a rule, such exposures are of small extent and often much obscured by the heavy talus almost everywhere present. While the county has produced a large quantity of stone for local use, and is capable of producing much more, there is not a single worker in the county who depends upon the quarry industry for a livelihood.

The following sections will give a fair idea of the natural resources of the county along this line.

Walgren's Quarry, southwest quarter of the southeast quarter of section 3, Lockridge township.

	FEET.
4. Soil and drift of variable thickness.	
3. Clay and marl, yellow	3½
2. Limestone, dark gray, porous, somewhat cherty in places	7
1. Limestone, grayish yellow, exposed	5

Monson's Quarry, northeast quarter of the northwest quarter of section 8, Lockridge township.

	FEET.
6. Soil and drift of variable thickness.	
5. Limestone, compact, fine-grained, almost lithographic in texture, pyritic	1½
4. Limestone, soft, gray, in thin beds	2
3. Limestone, gray, in a single ledge	2½
2. Limestone, dark gray, compact and slightly bituminous	½
1. Marl, blue, shaly, exposed	½

Numerous sections are exposed along Walnut and Burr Oak creeks and their tributaries in the three northeastern townships. The hard beds are quite generally brecciated and are associated with marly and shaly layers.

In the southern portion of the county outcrops are fewer. Near the south line of Round Prairie township, a quarry has been opened in the southwest quarter of the southeast quarter of section 34. The section is given herewith.

	FEET.
4. Soil and drift of variable thickness.	
3. Marl, gray, fossiliferous	2
2. Limestone, white, with a ledge of very fine, almost lithographic texture	2
1. Limestone, gray, in ledges varying from six inches to one foot in thickness, with shaly parting near the middle	5

Other exposures occur in Round Prairie, Cedar and Liberty townships. Quarrying has also been done to the northeast of the center of section 10, in Liberty township. The beds worked are as follows:

		FEET.
7.	Soil and drift of variable thickness.	
6.	Shale, green, pockety, belonging to Coal Measures.	
5.	Limestone, gray, weathering into rounded bowlders, in places with small crevices filled with calcite, fossiliferous.........	4
4.	Marl, light colored, with occasional stone concretions, fossiliferous......	2
3.	Limestone, gray..........	½
2.	Marl, similar to number 4..................................	3
1.	Limestone, gray, pyritic..	3

Practically all good quarry stone belongs to the Pella beds, and comprises heavy ledges of compact limestone, alternating, especially above, with seams of greenish, marly shales. Occasionally the limestone is slightly broken up and brecciated, but to a much less extent than the Verdi beds below. Some of the beds are almost lithographic in character. The beds are usually more or less pyritic throughout.

KEOKUK COUNTY.

The Saint Louis limestone immediately underlies the drift over three-fourths of the county. While its three divisions are represented, only the Verdi beds are of sufficient importance to merit consideration commercially. The Springvale beds have been recognized at Springvale Mills, in the upper portion of the Cook quarries north of Ollie, and at one or two other points along the Skunk river. These beds comprise a blue, earthy limestone of marked shaly character, which weathers readily into a soft, brown to buff limestone. It is magnesian and often presents an arenaceous facies. Clean cut exposures are rare on account of its weathering properties. The beds occasionally present a pseudo-conglomeratic character as seen in the Cook quarries. They rest unconformably on the Osage limestone, and aggregate twenty to twenty-five feet in thickness.

The middle member of the Saint Louis, the Verdi beds, covers the larger portion of the county, and affords the principal limestone outcrops, and the only limestone quarries in the county with the exception of those northwest of Ollie. Typical exposures may be viewed along both branches of Skunk river, English river, and along the creeks north and west of Sigourney.

The beds present comprise fine-grained, light colored, calcareous sandstones in bands two to six feet in thickness, inter-bedded with the limestone. In places, however, clean sandstones of much greater thickness, up to thirty or even forty feet, with limestone above and below, are seen. The most usual type of limestone is of a light ash to buff color, fine-grained, exceedingly compact and hard, almost cherty in character. This is the limestone found inter-bedded with the sandstone. A second equally well known type comprises the brecciated beds. In these beds, the limestone is broken up into irregular fragments and cemented together, the whole forming a distinct calcareous conglomerate or breccia. The usual cementing material is calcareous, though ferruginous material is sometimes present. The rock fragments appear to possess the characteristics of the Saint Louis limestone itself. They vary greatly in size, ranging from grains a fraction of an inch in diameter to slabs and blocks four feet long and six to eight inches in thickness. The brecciated blocks are usually one or two inches in diameter. Local unconformities, false bedding, and other irregularities are not uncommon structural features.

A few of the numerous sections exposed are given below and are believed to be fairly representative.

The following beds are exposed in a railway cut about one and a half miles west of Ollie:

		FEET.
7.	Soil and bowlder clay	10
6.	Sandstone, cross-bedded, yellow, fine-grained; becoming harder for six inches and apparently calcareous below	6
5.	Limestone, compact	⅔
4.	Marl and limestone	⅓
3.	Limestone, fine-grained, grading into number 2	⅓
2.	Limestone, finely brecciated, in places almost oölitic	2
1.	Limestone, compact, exhibiting conchoidal fracture, exposed to track	6

Several small quarries have been opened from time to time along Sugar creek near Showman station. Here the beds are very irregular and false bedding on a large scale is well shown. A typical section is about as follows:

		FEET.
6.	Soil and drift of variable thickness	0–30
5.	Limestone in fairly even ledges	4
4.	Talus, shale or marl	3

	FEET.
3. Limestone in heavy ledges, shaly below, shows a decidedly concretionary facies when weathered	4
2. Limestone, hard ledge, separated from number 1 by a shaly parting, brittle and compact	1½
1. Sandstone, cross-bedded and unevenly indurated, dip of bedding planes inconstant, but ranging up to 35 degrees	10

Number 5 furnishes the principal quarry rock of the neighborhood. Number 2 apparently rests unconformably upon number 1.

Numerous small quarries have been worked at one time or another north and west of Sigourney. The Miller quarry located about two miles north of town may be taken as an example:

	FEET.
4. Soil and drift almost *nil* at the quarry face, but thickens greatly in the bluff	2+
3. Limestone, similar to number 1, with arenaceous to argillaceous partings; less evenly bedded than 1 and weathers concretionary; calcite lenses and nests present	3-6
2. Sandstone, with shaly partings, fine-grained, and but slightly indurated	2
1. Limestone, hard and compact, gray, evenly bedded, beds ranging from 4 to 12 inches in thickness; numerous pyritic balls present, mostly weathered to limonite	6

The beds dip strongly to the east, and do not appear to be persistent in character. The stone crops of the region appear to rise about forty feet above the creek. The sandstone as a rule is the most conspicuous member, is heavily bedded but imperfectly indurated.

Outcrops in English river are less common than along the Skunk, but are in a general way, repetitions of those already given.

The quarries of the county, while numerous, are small and without exception, are of local importance only.

LEE COUNTY.

The Saint Louis limestone comprises some of the most important rock formations in Lee county, occupying about one-third of its superficial area. Numerous outcrops appear along the streams in West Point and Franklin townships, and in the bluffs below Montrose on the Mississippi and along the Des Moines above Sand Prairie.

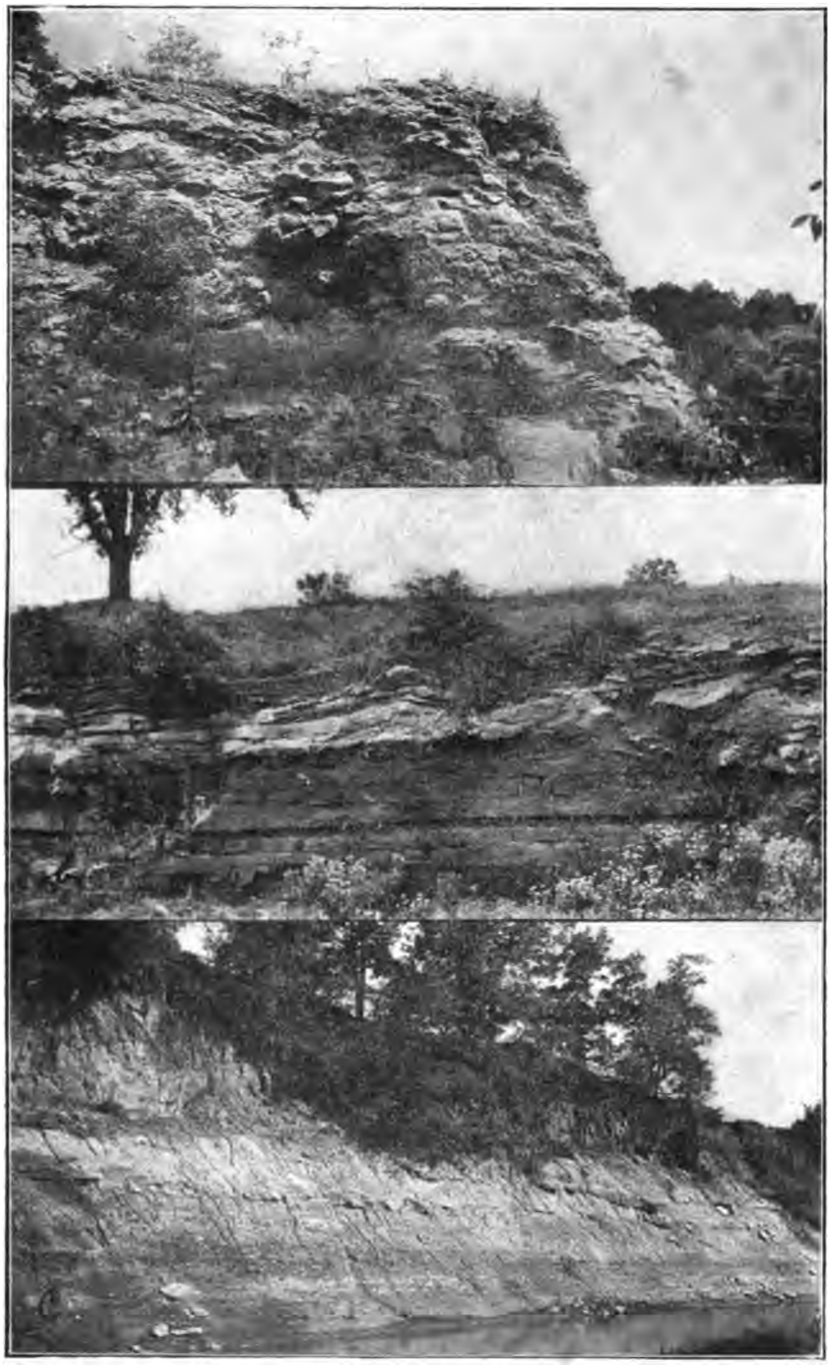

PLATE LVI—a. Abandoned Santa Fe quarry east of Belfast, Iowa.
b. Principal quarry section southwest of Mt. Pleasant, Iowa.
c. Geode bearing shale, west of Farmington, Van Buren county, Iowa.

According to Keyes and Gordon, the Saint Louis consists of a lower magnesian or somewhat sandy limestone, grading at times into a calcareous blue sandstone and an upper white compact or granular limestone. A brecciated zone often separates the two members. From a study of the field relations of the above beds and those already discussed under the head of the Osage, it would appear that the upper or so-called Warsaw beds of the Osage are the same as the arenaceous member of the Saint Louis of Keyes and Gordon. Whatever the taxonomic relations of these beds may be, both members of the Saint Louis as given above are quarried to some extent, the limestone being the more highly prized, in the numerous outcrops available.

The sections given below give a fair picture of the leading characteristics of the beds.

A mile west of Sand Prairie the Saint Louis appears in several ravines opening into the Des Moines valley, and from these some stone has been produced for local use. One-half mile above Hillsdale, the Santa Fe Railway worked extensively years ago. The section is shown as follows:

		FEET
6.	Soil and drift	6+
5.	Limestone, brecciated, with pockets of green clay, sometimes rudely and coarsely stratified	30
4.	Limestone, blue, encrinital	3
3.	Shale, blue, calcareous	3
2.	Sandstone, blue, calcareous, with discontinuous beds of blue shale; the principal quarry rock	8
1.	Shale, blue	15

The stone was used largely for bridge work; the rubble and small sizes were put through the crusher.

Just below Belfast some quarrying has been done. The stone was used largely by the Chicago, Rock Island and Pacific Railway for bridge work. The section quite closely resembles the Santa Fe quarry, though the sandstone horizon was more extensively developed. The section which may be seen at the present time is as follows:

BELFAST SECTION.

		FEET.
5.	Soil and drift, which thicken considerably back in the bluff, variable at the face.	
4.	Limestone, earthy, yellowish, gray to blue-gray, weathers clayey; probably attains much thickness in the bluff, exposed	4
3.	Limestone, brecciated and concretionary and shaly, in places. The concretions appear to be compact, brittle, blue limestone, uniform neither in thickness nor in appearance	4
2.	Limestone, arenaceous, especially below, fossiliferous; gray to blue-gray; thinly bedded, although bedding planes are not apparent	8
1.	Sandstone, calcareous, or limestone, highly arenaceous, in heavy beds up to five feet in fresh exposures; beds rather uneven and show some tendency to wedge; cross bedding is evident in places, exposed	12

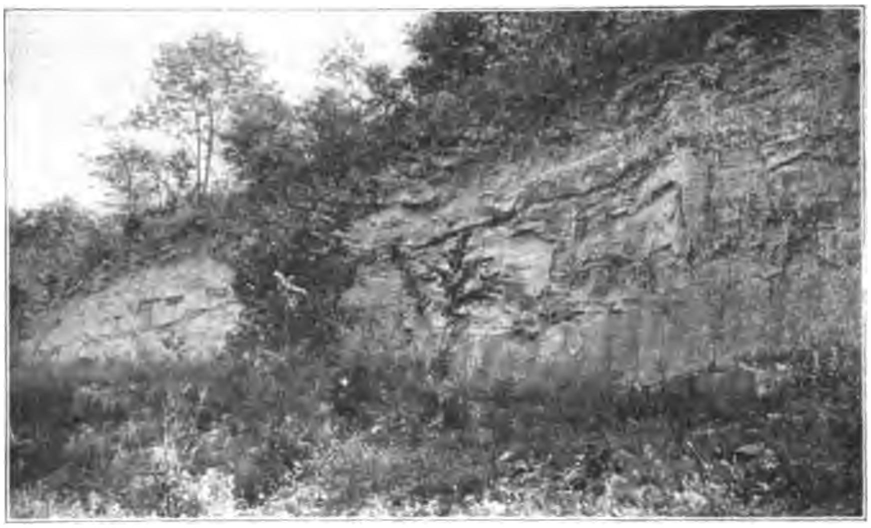

FIG. 31.—Section along the C., R. I. & P. Ry., below Belfast showing Warsaw sandstone below and St. Louis limestone above. Van Buren county, Iowa.

The base of the section is about four feet above the railway track. No quarrying is being done at the present time. About a fourth of a mile below the railway station in Belfast, twenty feet of plastic shales are exposed along a small creek entering the Des Moines from the east. The shale appears to be quite uniform in character throughout and lies clearly below the beds in the above sections. The section continues about one hundred yards up stream, where it is obscured by talus. Near the east end of the outcrop, a weathered cap-rock appears at just about the level of the Chicago, Rock Island and Pacific railroad track. The depth of the shales below the stream channel is unknown. An average sample of the shales was collected and analyzed. The analysis is as follows:

CHEMICAL ANALYSIS OF BELFAST SHALE.

Silica	45.00
Alumina	16.68
Ferric oxide	3.86
Lime	10.04
Magnesia	3.69
Sulphur trioxide	2.26
Potash	1.96
Soda	1.16
Loss on ignition	15.02
Moisture	0.48
Total	100.15

Exposures of Saint Louis continue up the Des Moines river but almost no quarrying is done at the present time, and no new phases are shown.

One of the best sections exposed in the interior of the county is located along Sugar creek about one and a half miles east of the town of Franklin. The following beds are exposed:

GRANER QUARRY.

		FEET.
10.	Drift	10
9.	Limestone, white, granular, oölitic, even-textured, more or less distinctly cross-bedded	8
8.	Limestone, sub-crystalline	2
7.	Limestone, blue, concretionary	1
6.	Shale, blue	½
5.	Limestone, granular, oölitic	6
4.	Limestone, brecciated	10
3.	Limestone, brown, arenaceous	8
2.	Shale, blue	10
1.	Shale, blue, with geodes	20

Beds 5, 7 and 8 dress well and have been used in making tombstones. Number 3 has been used for all kinds of rough masonry and for bases for monuments. All the layers were used formerly for manufacturing lime, but number 7 was the best for this purpose.

LIME.

While all of the limestone formations of the county have been used from time to time in the manufacture of lime, the Saint Louis was used most extensively. The chief lime centers were the city of Keokuk, and some localities east of Franklin and northwest of Denmark. The industry is practically extinct at the present time.

MAHASKA COUNTY.

All of the more important streams crossing the county have cut through the drift and overlying Coal Measures to the subjacent limestone, at least throughout the greater portion of their courses. The beds represented are believed to be equivalent to the upper beds in Marion county, which are generally known as the Pella beds. Small quarries have been opened from time to time at a number of points, mainly along the two branches of the Skunk river. Perhaps the most important quarry section may be viewed in the Mayer quarry about two miles north of New Sharon near the North Skunk. The section is as follows:

		INCHES.
9.	Drift and Coal Measures of indefinite thickness.	
8.	Limestone	6
7.	Limestone	5
6.	Limestone	5
5.	Limestone	14
4.	Limestone	20
3.	Limestone	8
2.	Clay-shale	6
1.	Limestone, exposed.	

The stone exposed is fine-grained, compact, ash colored to gray limestone, brittle and breaking with a conchoidal to uneven fracture. The above divisions represent ledges which are separated by clay partings. Less important exposures occur at Union mill and McBride mill on the North Skunk; near Peoria and near the Oskaloosa water works on the South Skunk; in the vicinity of Bellefountaine on the Des Moines river and along Muchakinock creek. The same thin-bedded, compact, brittle limestone characterizes all of the leading quarry exposures.

Lime was burnt in a small way some years ago but the industry was never of more than local interest.

MARION COUNTY.

The Saint Louis limestone appears only in the eastern half of the county and there only along the South Skunk and Des Moines rivers and their immediate tributaries. Only the two upper substages are exposed, the Verdi beds overlain by the Pella beds. The former beds are not persistent and comprise a rather complicated series of sandstones, cherty limestones, clays and shales. The upper beds are prevailingly limestones, fairly low in magnesia and other impurities. While both formations have been exploited to some extent, quarrying operations have been confined largely to the upper beds.

One of the most extensive sections exposed in the county occurs about two miles southwest of Tracy, on the southeast quarter of section 35 in township 76 north, range XVIII west. The sequence is as follows:

TRACY SECTION.

		FEET.
7.	Loess and drift of indefinite thickness	2–10
6.	Sandstone, argillaceous, much weathered and iron-stained	6
5.	Shale, arenaceous, variable in color and state of induration	4
4.	Limestone, argillaceous to arenaceous, weathers decidedly shaly	4
3.	Limestone, similar to 1, but harder; in a single heavy ledge	2
2.	Limestone, argillaceous, but hard and brittle, splits into thin layers on exposure; highly fossiliferous above and below	4
1.	Limestone, gray-blue, in heavy beds, finely brecciated, fossiliferous and slightly crystalline; in three ledges	4

Numbers 1 to 4 inclusive are referred to the Pella beds. Numbers 1 to 3 are the principal ledges quarried and appear to be well adapted for dimension stone, rubble and possibly bridge stone. Number 2 yields a fair flagstone. The individual ledges in numbers 1 to 3 are uniform in thickness and appear to be persistent. The layers are fine-grained, oftentimes bluish when first exposed, but turn white when long exposed to the weather. Number 6 appears to be quite compact when fresh, and large blocks may be removed. When exposed to the atmosphere, the blocks disintegrate rapidly to a drab product resembling clay. It is highly fossiliferous throughout.

A switch of the Chicago, Burlington and Quincy railroad has been laid into the quarries. These have been opened up on the north bank of Cedar creek for a distance of more than half a mile.

In the vicinity of the town of Harvey the limestones belonging to the Pella beds of the Saint Louis and the Lower Coal Measure strata are exposed at many points in the valley of English creek and along the west border of the Des Moines valley. They appear also in the hillsides along the ravines and small streams in sections 10 to 15, Clay township. All of the exposures of the Pella limestones observed in this vicinity are covered with a greater or less thickness of the Des Moines shales and glacial drift. As a rule the amount of these materials is so great as to prohibit the quarrying of the limestone. Prospecting has shown, however, that there are considerable areas in the north part of section 15 and the south portion of 10 where the limestone lies from but fifteen to twenty feet below the surface, and where the covering is said to consist largely of shales. This association of the shales and limestone is favorable to their use for cement manufacture. Near the southeast corner of the southwest quarter of section 10, eleven feet of thin bedded white and fairly uniform limestone outcrop in an old quarry face. One-eighth mile distant to the east the stone is seen at a higher elevation in the hillside. Test holes are reported to penetrate not over eight feet of worthless overburden over forty acres at this place, the remaining beds above the stone being clean shale. The limestone is reported by the driller to extend to a depth of twenty-two to twenty-five feet, which would bring the base of the bed near the level of the Des Moines flood plain.

Chemical investigations and burning tests of blends of the shale and limestone prove their suitability for making a good quality of Portland cement. A company is now engaged in exploiting the deposits and options are held on a large acreage lying mostly to the south of Harvey but including land also near the Rock Island railway on English creek. It is proposed to erect here a plant of large capacity and to make use of the Des Moines shales and underlying limestone that are found in this district. Transportation facilities on three railroads afford good outlets for the finished product. Coal is now being mined on land optioned by the company and prospecting shows the

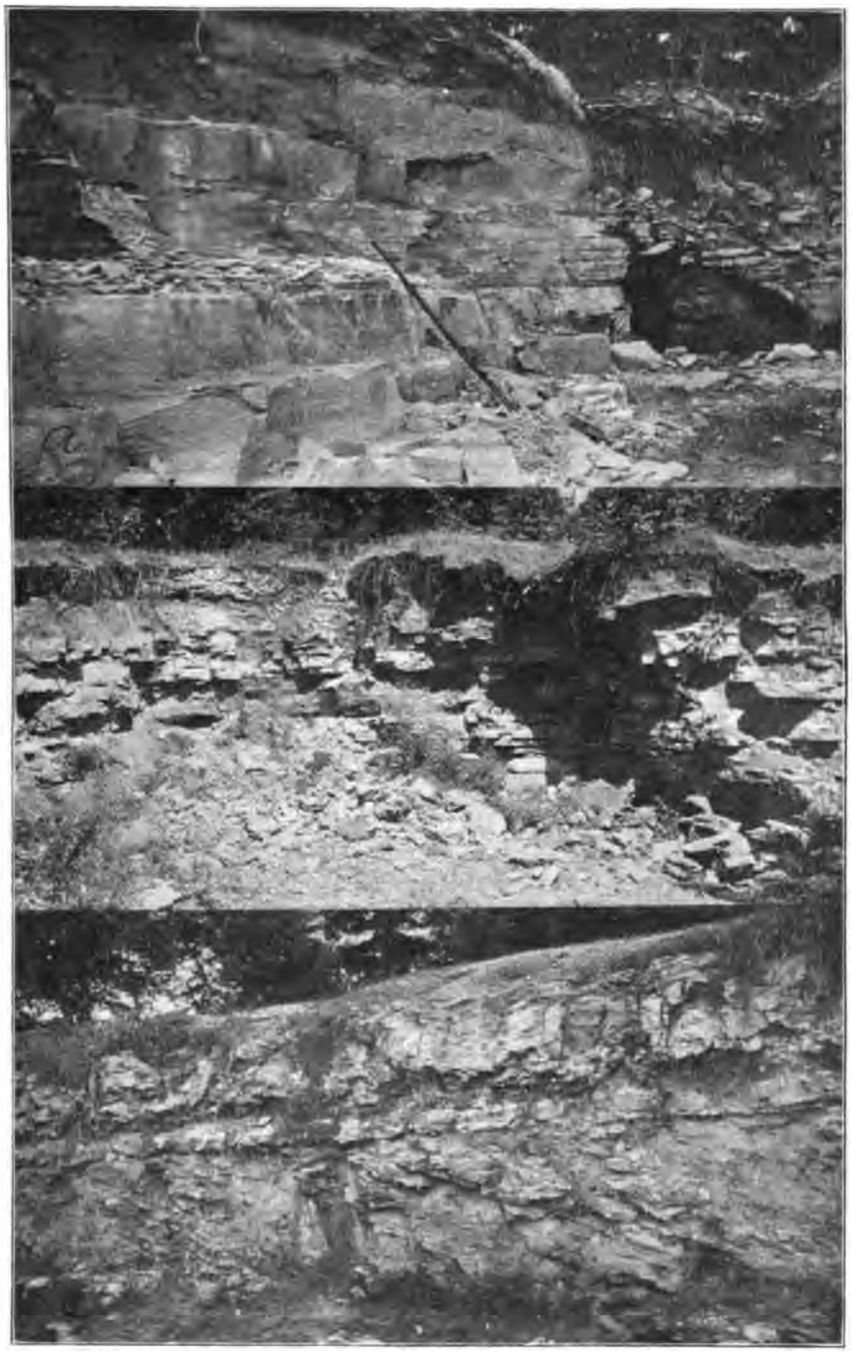

PLATE LVII—a. Near view of quarry face, Tracy, Marion county, Iowa, showing Pella beds.
b. Miller quarry, about two miles north of Sigourney, Keokuk county, Iowa, showing Pella beds.
c. Local unconformity in Verdi beds, near Showman station, Keokuk county, Iowa.

presence of a heavy vein underlying contiguous territory which will furnish an abundant supply of a fair grade of fuel.

Good exposures of the Verdi beds may be viewed along the Skunk river in Lake township, especially in sections 23, 24 and 26. A composite section for the district shows the following beds:

		FEET.
6.	Loess and drift, of variable thickness.	
5.	Sandstone, buff, cross-bedded, lower part very soft..........	5
4.	Limestone, massive, cherty, breaks irregularly..............	4
3.	Sandstone, gray, soft to quartzitic in places.................	3
2.	Limestone, cherty..	2
1.	Sandstone, massive, yellow, with interbedded arenaceo-calcareous bands one-half inch to four inches in thickness. These bands are very hard, compact, fine-grained, and are more resistant to weathering than the sandstone, so that layers stand out on weathered surfaces. Occasional irregular fragments of this limestone, 1 to 2 inches in diameter, are found in the sandstone; exposed	20

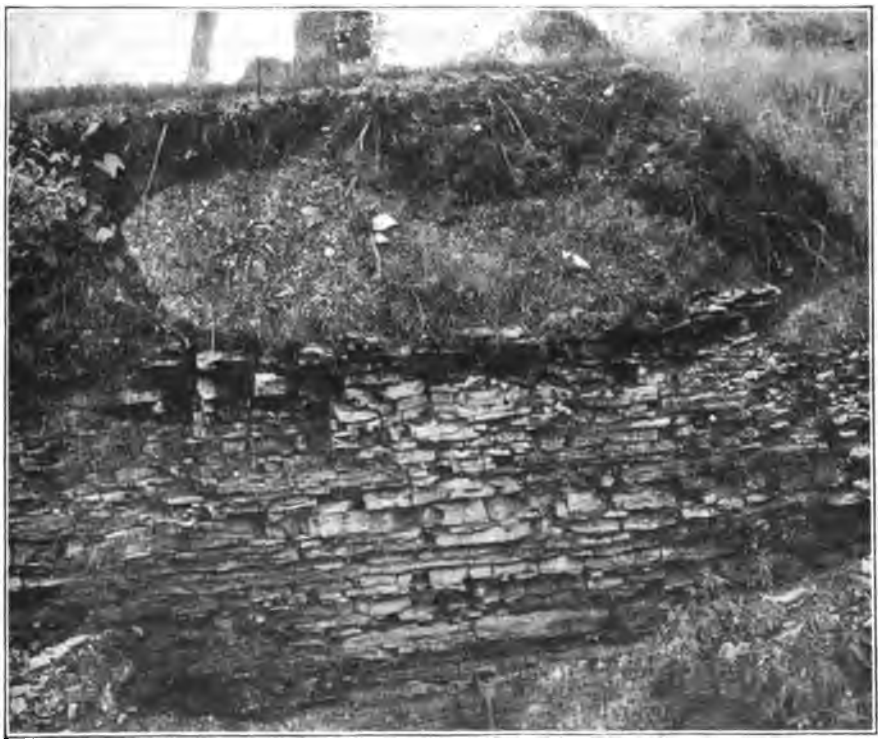

FIG. 32—Exposure of Saint Louis limestone, near Harvey, showing Pella beds.

Number 4 is quarried to some extent, the product being used for rough masonry. The heavy overburden and the difficulty of producing regular blocks preclude any possibility of its extensive use as a coursing stone.

The Pella beds have been quite extensively developed at Durham and between Durham and Flagler; southwest of Pella on the Pella-Knoxville road, and north of Tracy. The quarry opened between Durham and Flagler, between the Chicago, Rock Island and Pacific and Chicago, Burlington and Quincy railways, shows the following sequence of beds:

		FEET.
5.	Loess and drift	3
4.	Limestone, thinly bedded	6
3.	Limestone, in well defined ledges, varying from 6 to 20 inches in thickness	5½
2.	Limestone, soft, granular, of little value for structural purposes	1½
1.	Limestone, very hard, breaks irregularly	3

A twenty inch ledge near the middle of number 3 is the principal layer in the quarry. It is coarse-grained, dark colored, but weathers white. The vertical joint planes are a sufficient distance apart to permit the removal of blocks of large size. Much of the product from this quarry and the old quarry northeast of Durham has been shipped to points along the Chicago, Rock Island and Pacific railroad as far east as Washington, Iowa. Most of the stone used for structural purposes and flagging in Pella has been obtained from two quarries located about one and one-half miles southwest of the town on the Pella-Knoxville road. The beds exposed are very similar to those which are shown in the preceding section, save that an extensive deposit of marl similar to that which occurs in the Tracy quarries overlies the limestone.

The Durham-Flagler section is almost exactly duplicated in a quarry opened on the southeast quarter of section 13, in Clay township, about three miles southeast of Harvey. The beds exposed here are as follows:

		FEET.
5.	Loess and drift, of variable thickness.	
4.	Limestone, thinly bedded, greatly fractured	5
3.	Limestone, in ledges varying from 4 to 20 inches in thickness	5
2.	Shale, black above and gray below, soft	1½
1.	Limestone, thinly bedded, crystalline	1

Here as before a twenty inch ledge just below the middle of number 3 is the principal ledge in the quarry. It is granular in texture, with vertical joint planes from four to ten feet apart.

While the beds which comprise the Pella sub-stage are persistent and uniform in texture, and of convenient and sufficient thickness for building and other structural purposes, they will probably never be extensively developed on account of the small aggregate thickness of the beds which are usable as compared with the amount of overburden and worthless layers which must be handled. Some of the upper beds will not stand alternate freezing and thawing, and should not be used in permanent structures. The principal ledges, however, appear to withstand weathering indefinitely as indicated by their fresh appearance, both in natural quarry sections and in walls which have been exposed to the elements for more than twenty years.

The following tests were made by Professors Marston and Weems on specimens secured from the Tracy quarry:

CRUSHING TEST.

Stone	Height In Inches	Cross Section Square Inches	Breaking Stress—Pounds Per Square Inch	
			Spalling	Failure
No. 31, Saint Louis Limestone.....	1.95	4.12	7,300	9,500
No. 32, Saint Louis Limestone.....	2.00	4.20	5,200	9,900

ABSORPTION TEST.

Stone	Per Cent of Increase		
	24 Hours	Week	Total
No. 31, Saint Louis Limestone............	2.28	0.99	3.27

CHEMICAL COMPOSITION.

Calcium carbonate ($CaCO_3$)..................................	94.60
Magnesium carbonate ($MgCO_3$)	3.17
Alumina (Al_2O_3)..	0.49
Iron oxides ($FeO+Fe_2O_3$)..................................	0.17
Insoluble..	1.57

Lime was burned in sufficient quantity to meet the local demand in the early history of the county, but the industry has been abandoned.

POCAHONTAS COUNTY.

But a single exposure of the indurated rocks is known in this county. The Saint Louis has been quarried for a number of years two miles north and one mile west of Gilmore. The quarry is now owned and operated by Andrew Bull. The opening is far less extensive than formerly, but the following beds may be observed:

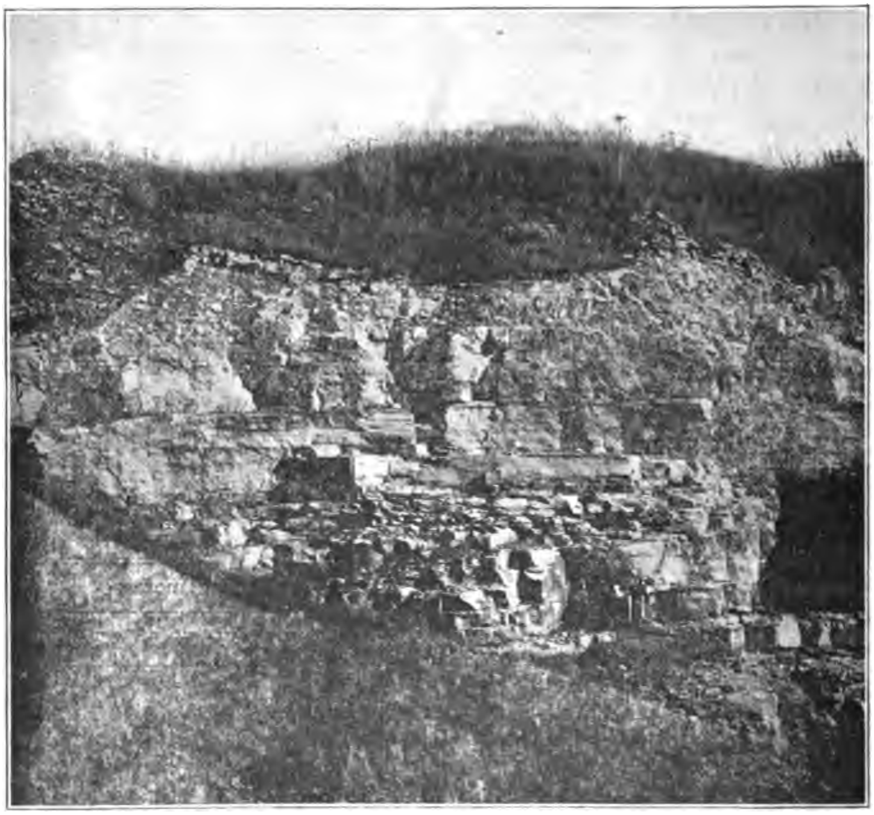

FIG. 33—Saint Louis limestone beds as they appear near Gilmore, Iowa.

		FEET.
11.	Soil, sand and gravel	5
10.	Crystalline limestone, light brown in color; cavernous due to weathering, much shattered and of little value	4
9.	Limestone, light brown, coarse in texture and sub-crystalline, splits well with bedding planes, but in an irregular manner vertically, heavy bed	3
8.	Ledge, as above, underlain with two inches plastic, variegated red and greenish clay	1½
7.	White to pinkish brown limestone, in part fossiliferous; beds broken by vertical joint planes along which water has formed many small caverns and on which small pyrite nodules and fossils stand in relief. Ledges running two inches up to three feet in thickness	10

[*]T. H. Macbride in *Geology of Humboldt County* gives the following additional strata then visible below the above section:

		FEET.
6.	Blue shales, limestone and clay; very fossiliferous	2
5.	Lithographic limestone, much inclined to angular fracture	1½
4.	Heavy-bedded, fine-grained limestone, no fossils	3
3.	Shaly, thin-bedded limestones, with few fossils	1
2.	Coarse-grained, fossiliferous limestone, containing fragments of No. 1, but separated from it by a parting of shale	1
1.	Lithographic limestone, fine-grained and very hard	2

This author regards the lowest beds as equivalent to those quarried at Humboldt in the adjoining county to the east.

Numbers 7, 8 and 9 constitute the principal quarry rock. An analysis made of a sample from these members is given herewith:

Silica (SiO_2)	0.32
Calcium carbonate ($CaCO_3$)	99.62
Water and undetermined	0.06

J. B. WEEMS, analyst.

A casual inspection of this analysis shows the limestone to be almost absolutely pure and it appears to be of high quality.

The quarry is located in the lowest portion of a broad depression which appears to be the site of a former pond or sinkhole. It is a local center of drainage and some trouble with water has been encountered. The drift overburden varies from five to ten feet at exposures, but there is a considerable area in which the stone probably lies at no great depth beneath the surface. The Des Moines and Ruthven division of the Chicago, Rock Island

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[*] Iowa Geological Survey, Vol. IX, p. 132.

and Pacific Railway traverses the depression and a switch formerly extended to the quarry. The stone is now hauled one-fourth of a mile to the railroad, and although the quarry is in constant operation, the annual output is small. Excellent dimension stone for all purposes is afforded. The equipment consists of one large derrick operated by an engine. The ruins of an old lime kiln indicate that this industry has formerly been of some importance.

STORY COUNTY.

Story county is poorly supplied with stone suitable for structural purposes. The Saint Louis limestone affords a limited quantity of stone adapted to foundation work and use in the rougher grades of masonry. The rock is, as a rule, highly absorbent and does not stand frost well. Its earthy buff to gray-buff color gives it a dull, somber appearance which increases rapidly on exposure on account of the readiness with which it takes up foreign matter. Some quarrying has been done at nearly every one of the outcrops in the county, though in no instance does the annual output of any single quarry exceed a few dozen cords of rough stone. The ledges developed are practically the same at all points and are confined to Skunk river between Bloomington and Soper's mill, and to Onion creek, a tributary of Squaw creek, northeast of Ontario. The section exposed north of Hannom's mill may be considered a fair average for the Skunk river district, and is as follows:

		FEET.
6.	Till, pale yellow; unoxidized and unleached	0-6
5.	Till, oxidized to a deep reddish brown and thoroughly leached; much weathered limestone and many decayed granite bowlders, and numerous, tolerably fresh greenstones present	1-3
4.	Limestone, residual; reduced to an iron-stained, cavernous chert	1
3.	Limestone, arenaceous, where unaltered, a bluish gray, but weathering stains it a yellowish brown; not thoroughly indurated, though when unweathered presents a massive appearance	5
2.	Sandstone, bluish gray; shaly, presents a fissile character after being exposed to the weather, and forms a marked re-entrant in the quarry face	3
1.	Limestone, impure, buff to earthy-yellow, gray-buff when unweathered, heavy-bedded, compact; lithographic in part, chief quarry stone; exposed	8

At the Bloomington quarries more of number 1 is exposed.

Several outcrops of the Saint Louis may be observed along Onion creek in section 32, Franklin township. The beds exposed attain a maximum thickness of nearly thirty feet, but are less constant in character than their equivalents along Skunk river. A composite section representing the district is as follows:

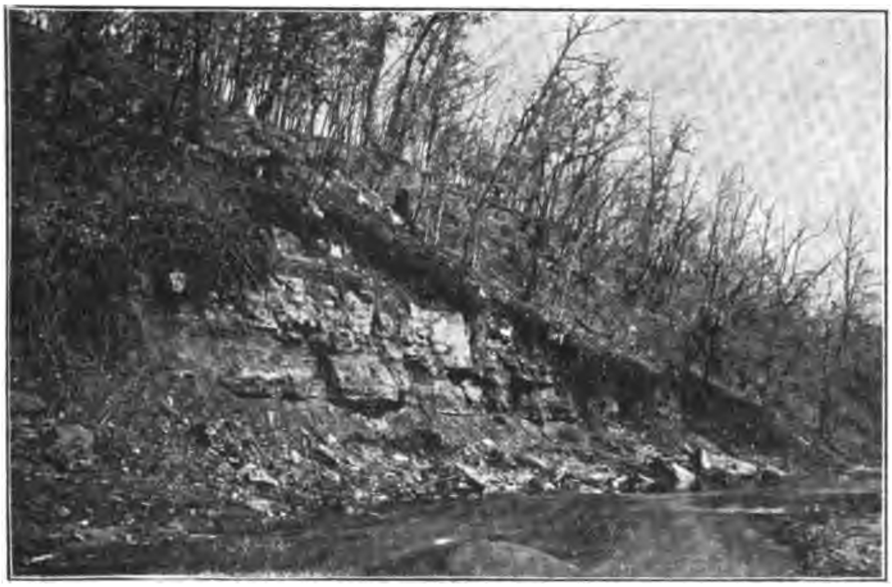

FIG. 34—Representative section of Saint Louis limestone, as it appears along Onion creek, about four miles northwest of Ames, Iowa.

		FEET.
7.	Drift and soil of variable thickness, in places reduced almost to zero, but thickens greatly in the bluffs	1-70
6.	Limestone, thinly bedded and much weathered, stratification planes almost entirely eliminated; in places grading upward into a residual clay	4
5.	Limestone, impure, yellowish brown, or gray-brown, compact to earthy, heavy-bedded	7
4.	Limestone, finely arenaceous and marly, contains beautifully preserved mud cracks and ripple marks in places	2
3.	Sandstone, white to bluish gray, friable; obliquely laminated and fissile; readily undermined by the creek; not persistent	1½
2.	Limestone, cherty and concretionary; contains much limonitic iron	2
1.	Sandstone, argillaceous; becoming shaly below, exposed	3

Number 5 is the principal bed quarried and is very similar to the leading quarry rock developed in the Hannom's mill and Bloomington quarries.

VAN BUREN COUNTY.

Gordon thus described the beds of the Saint Louis stage as they occur in Van Buren county:*

"The Saint Louis limestone constitutes the uppermost division of the Mississippian, . . . and has the greatest superficial extent of any of these members in Van Buren county. It is generally overlain by the rocks of the Des Moines stage of the Upper Carboniferous. . . . The maximum thickness in Van Buren county probably does not exceed ninety feet.

In lithological characters the rocks composing the formation show great variation. In general they present a three-fold division consisting of (1) brown arenaceous and magnesian limestone, (2) brecciated limestone, and (3) grey, compact, and granular limestone.

Arenaceo-magnesian Beds. The first of these is exposed at many places along the Des Moines and is especially well developed in the vicinity of Kilbourn and in the bluffs below Keosauqua. It consists of fine-grained or vesicular magnesian limestone in rather heavy ledges, which grade horizontally into a more or less clearly marked arenaceous rock characterized in places as a sandstone. A large percentage of the rock, however, is made up of calcareous matter, and hence it is more properly designated as an arenaceous limestone. It is well developed on Price and Bear creeks where it furnishes a very good quality of stone for building purposes, and has been quarried quite extensively for plates and sills. This bed represents that quarried at Belfast and Keokuk. It constitutes the upper member of the Warsaw as originally defined. The arenaceous character is confined generally to the lower part of the beds, but on Bear creek as well as elsewhere, sand forms the larger part of the formation. The magnesian limestone constitutes the most generally recognized phase of the division in the county. When first removed from the bed, the rock is of a blue or drab color, but it soon changes to a rusty brown by the oxidation of the iron which it contains.... The magnesian rock occurs in thick, gently undulating beds, and is distinguished by a more or less concretionary structure.... In places these beds are interrupted by the brecciated phase which in these instances is in direct continuity with that of the overlying bed. The thickness of the arenaceo-magnesian beds varies from ten to twenty-five feet.

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*Iowa Geological Survey, Vol. IV, p. 214.

Brecciated Limestone is a widely recognized phase of the formation in Iowa. The bed is made up generally of compact and granular, grey limestones, in sharp angular fragments of various sizes cemented together by similar calcareous material."

Near the mouth of Reed creek, the whole of an exposure seventy-five to eighty feet in height shows brecciation. The lower portion represents the arenaceo-magnesian bed and is composed of large fragments of this limestone with clay filling the interstices, while the upper part is made up of the compact and granular limestone more completely cemented. In the vicinity of Keosauqua, the upper portion of the bed contains more or less arenaceous material. This is well marked on the south side of the Des Moines above the town, where a brown sandstone ten to twenty feet thick replaces nearly the whole brecciated division and is overlain by limestone. Two or three miles below, the sandstone varies from five to twenty-five feet in thickness and rests upon the brecciated bed, while it is overlain by the compact limestones as shown in the bluffs opposite Keosauqua.

Quoting again from Gordon:

"The sandstone at Keosauqua is decidedly calcareous in places, and sometimes includes irregular ledges and fragments of limestone.... The thickness of the brecciated division varies from nothing to seventy-five feet. In general, however, it may be said to be from ten to twenty feet thick.

Compact and Granular Limestone. Overlying the brecciated limestone in places, and the Keosauqua sandstone where that formation occurs, is a compact, fine-grained, grey limestone characterized by having a conchoidal fracture, concretions, and a considerable number of fossils.... In some places the compact limestone is replaced by a thin-bedded limerock with a marked granular structure often cross-bedded.... The limestone of this upper division is well developed along Indian creek where the compact variety is quarried quite extensively. The thickness of the bed does not exceed fifteen feet." "It is also quarried at Keosauqua on both sides of the river."

As pointed out, the Saint Louis beds have been more extensively quarried than the other formations of the county. Near the Des Moines river in the northwest quarter of section 31, Lick Creek township, the Saint Louis beds were formerly opened up for quarrying. A few feet of the upper arenaceous limestone has been quarried at Kilbourn and at other points on Lick creek but all these openings have been long since abandoned.

The white limestone has been quarried on Thatcher's creek on the southeast quarter of section 2, also on the southeast quarter of section 1, Des Moines township. Just east of the town of Keosauqua near the north edge of section 31, twelve to fifteen ledges have long been worked for foundation and rough building stone.

The Saint Louis beds have been opened up for local use at many places along Rock creek in Washington township. Gordon (page 220) gives the following section at the mouth of Rock creek:

ROCK CREEK SECTION.

		FEET.
6.	Concealed	5
5.	Limestone, compact, grey; breaking with conchoidal fracture; contains abundant brachiopod remains	6
4.	Sandstone, brown, quartzose	4
3.	Limestone, brecciated, well cemented	20
2.	Limestone, hard, blue, weathering brown; heavily bedded and concretionary; sandy at top, at base bluish and dolomitic in appearance	14
1.	Concealed to river level	35
	Total	84

Number 2 has been quite extensively quarried here for the early river improvements.

Northeast of Bonaparte on Mack creek and farther south on Reed and Potter creeks, the sandstone and brown magnesian strata have been quarried for use in locks and dams in river improvement work. The beds worked on Reed creek afford a stone which dresses well and has been used also for caps, sills and for well and cellar walls. It is said to be much more durable than the white limestone under the same conditions. Unlimited quantities of these strata are available along Potter and Reed creeks, where little stripping would be necessary and the quarries would be conveniently accessible to the railroad.

The blue sandstone has been quarried for many years on Bear creek in section 11, and a more recent opening has been made by Perry and Isaac Davis in the northwest corner of section 31, Henry township. The section at the latter place is given herewith:

		FEET.
7.	Drift, sand and gravel	2½–10
6.	Blue-gray "soapstone" shale with thin limestone layers in lower portion	6
5.	Arenaceous limestone, light brown, to bluish	2½
4.	Sandy blue magnesian limestone, "sandstone", solid ledge which splits readily with chisel parallel to bedding; some chert near base	5
3.	Irregularly bedded gray to blue, coarse-grained limestone, fossiliferous (bryozoan abundant)	5+
2.	"Soapstone," containing chert, to water in creek	1½
1.	White limestone reported to unknown depth	1½

Number 6 is plastic and appears free from concretionary matter. The maximum amount of stripping, about fifteen feet, is indicated in the section. Stone is shipped from this quarry but must be hauled to the railroad at Bentonsport. The sandstone gives good satisfaction in walls, and dresses well for use in more conspicuous and exposed parts of buildings. John Gaston has a small opening in the same beds one-fifth of a mile south on the opposite side of Bear creek.

A good development of the "sandstone" occurs also in the Price quarry on a tributary of Chequest creek in the southwest quarter of section 20, Van Buren township.

Section six miles northwest of Keosauqua along a small tributary of Chequest which enters the larger stream from the southwest:

		FEET.
7.	Drift and loess of variable thickness.	
6.	Limestone, much weathered and siliceous, certain layers weather shaly and are stained red to yellowish brown	2–4
5.	Limestone, blue-gray, evenly bedded and of uniform texture; very hard and tough, beds up to thirty inches in thickness	4

	FEET.
4. Talus slope.	
3. Limestone, gray, vesicular, coarser textured than number 5 and fossiliferous, partially obscured by talus slope; thickness not determined.	
2. Sandstone in heavy ledges, evenly bedded though beds are somewhat undulating; layers smooth enough to be used for dimension stone without tooling	10–12
1. Shale, calcareous to arenaceous, blue-gray, yellow where weathered; said to become more shaly below the bed of the stream; exposed	3

The sandstone beds range up to three feet in thickness, although blocks more than two feet thick were not seen in any of the sections exposed. It has been used extensively for bridge work and other heavy masonry. This stone was used for the piers which support the wagon bridge across the Des Moines river. It yields to any kind of stone dressing, is strong and withstands weathering influences well. Blocks put in walls or piers more than a half century ago still retain the tool marks, which appear to be as fresh as when the blocks were laid. On account of lack of transportation facilities almost no stone is quarried at the present time.

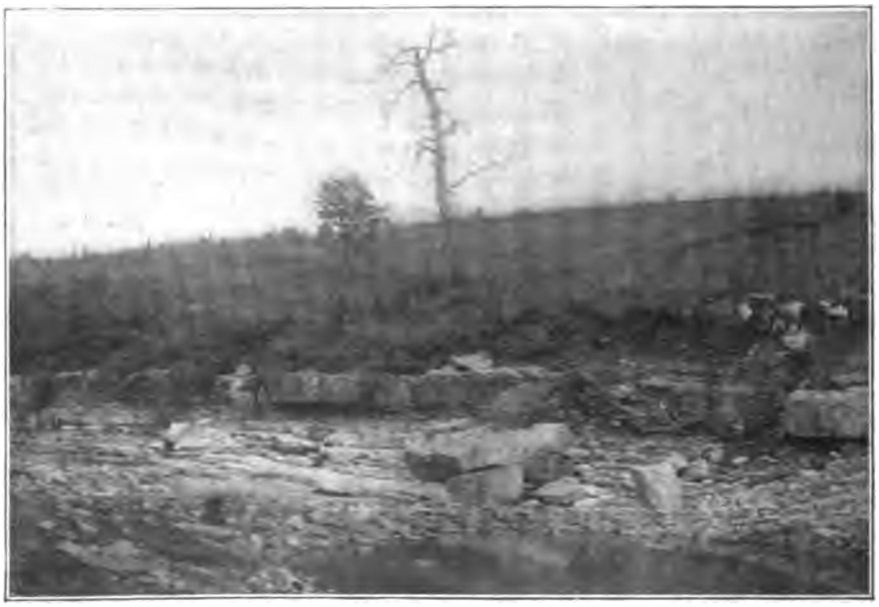

FIG. 35—Saint Louis limestone exposed along creek about three miles west of Farmington, Van Buren county, Iowa.

The Saint Louis limestone is well exposed all along Chequest creek from the middle of Chequest township to Pittsburgh. As indicated in the above two sections the lower portion of the magnesian limestone grades locally into a sandstone.

The large proportion of the stone used in the southern part of the county has come from the Indian creek quarries west of Farmington. Outcrops occur along this stream from near its mouth to the quarries on the line between sections 5 and 32 of Farmington township. The quarry in section 5 is now worked by Cyrus Falker and Mark Hornbaker. Limeburning was formerly done here. The strata now visible are given:

		FEET.
8.	Loess and drift	10+
7.	Limestone, gray, coarsely sub-crystalline, weathering to a friable condition; thin shaly layer at base	2½
6.	Limestone, homogeneous and fine-grained, with conchoidal fracture above; coarser and more impure below; separated into heavy ledges, the upper one 18 inches thick; stone traversed by seams of crystalline calcite which in general run vertically	5⅝
5.	Obscured	3½
4.	Soft shale, gray	4
3.	Limestone, heavy ledge; gray, compact, fracture conchoidal, irregularly shattered by weathering	2½
2.	Alternating bands of light blue to brown limestone and slaty shale	2
1.	Thin-bedded limestone, to water	3⅝

Only the members above No. 5 have been used. The upper three feet of No. 6 make a fair building rock. It is hard and weathers slowly. There is a considerable area on both sides of the creek where the stone is available without an excessive amount of stripping. The beds would afford a good product if crushed. The Chicago, Burlington and Quincy railroad follows Indian creek and would afford good transportation facilities.

Section one and a half miles west of Farmington, south of coal chute of Chicago, Burlington and Quincy railroad:

		FEET.
6.	Loess and wash, rather sandy and iron-stained and mottled throughout	5–20
5.	Shale, clayey, blue-gray	3
4.	Shale, arenaceous, hard, projecting ledge; variable	1–2
3.	Shale as above	3

	FEET.
2. Shale, arenaceous, forms a projecting ledge similar to 4, variable	1-2
1. Shale, somewhat variable in texture, varying from plastic and gritless to slightly arenaceous; as a rule becomes highly plastic on weathering; evidently fissile, blue-gray to dark blue; occasional concretions and geodes present. Exposed above creek channel about	8

About one-half mile farther west a massive sandstone appears in a cut along the railroad and below the railroad bridge the heavy bedded sandstone may be seen resting on the shales. The undercutting of the creek has produced and is maintaining an escarpment. The bedding planes in the sandstone are not apparent and the beds in the railway cut appear to be disturbed. The sandstone and shales appear to be the equivalents of those exposed along the Des Moines river below Belfast.

The association of the shales and limestones in the above section and the presence of the latter but a short distance to the eastward is favorable to their utilization in the manufacture of Portland cement. The chemical composition of an average sample of the limestone beds exposed in the Falker and Hornbaker quarry and of the blue shale exposed near the mouth of Indian creek is shown in the chemical analysis herewith:

	LIMESTONE	SHALE
Insoluble	10.14	.....
Silica (SiO_2)	.....	35.48
Alumina (Al_2O_3)	0.90	15.85
Ferric oxide (Fe_2O_3)	0.90	5.43
Lime (CaO)	49.67	12.56
Magnesia (MgO)	0.18	6.24
Potash (K_2O)	.....	1.59
Soda (Na_2O)	.....	0.26
Sulphur trioxide (SO_3)	.....	3.36
Carbon dioxide (CO_2)	.....	.....
Hygroscopic water (Hyg. H_2O)	0.15	1.88
Loss by ignition	.....	17.14

WAPELLO COUNTY.

In Wapello county the representatives of the Saint Louis stage that are of economic importance belong to the Pella beds, the upper division of the formation. Exposures are practically confined to the northwestern part of the county where the beds outcrop along the Des Moines valley from Eddyville to Ottumwa,

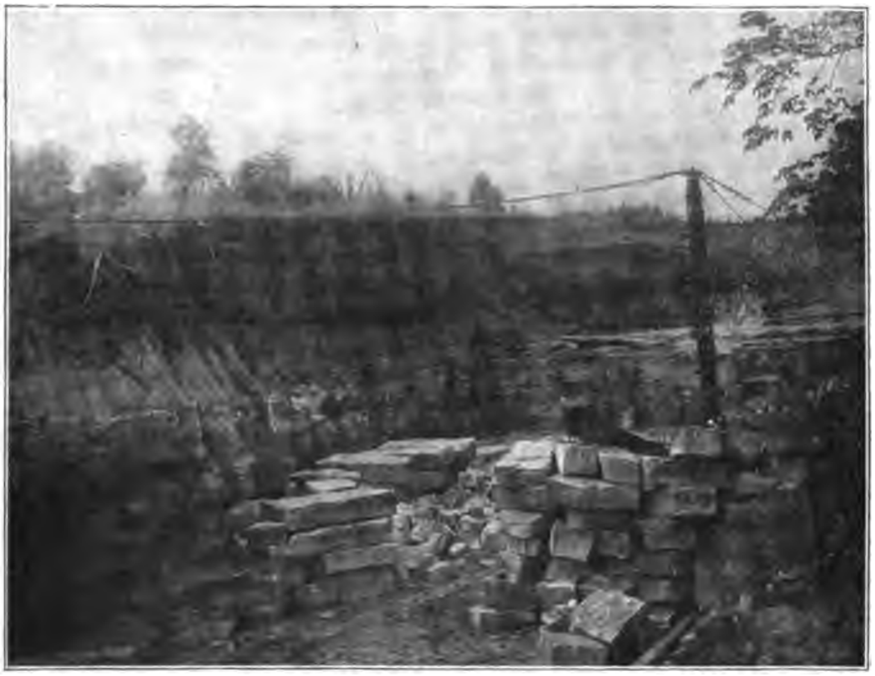

FIG. 36—John Lafferty quarry, Eddyville.

and on the North and South Avery creeks in the vicinity of Dudley.

Limestone was formerly quarried at a number of openings south of Eddyville, near the mouth of Miller creek. The John Lafferty quarry is the only one now in operation. It is located on Miller creek in the southwest quarter of section 7, Columbia township. The section exposed here for a distance of eight to ten rods, is as follows:

		FEET.
7.	Loess and river silt	5
6.	Residual clay, deep red, plastic	3½
5.	Residual clay, greenish, calcareous, grading into argillaceous limestone	3
4.	Compact limestone of lithographic texture and separated by marly partings; on exposure it becomes badly shattered by weathering of partings and vertical jointing	2½
3.	Heavy limestone bed, highly fossiliferous, upper portion contains cavities lined with calcite and abundant iron pyrite concretions; two ledges, respectively 14 and 22 inches	3
2.	Shell marl, a few inches.	
1.	Close-textured bluish limestone in 4 to 6 inch layers, to base of quarry	2½

Number 3 shapes readily and affords excellent stone for building purposes and for heavy masonry.

This quarry supplies stone which is used in bridge abutments in this and adjoining counties. The stone is handled by derrick and loaded on wagons. Considerable quantities have been shipped from Eddyville. There is a triangular terrace area here of considerable extent lying between the Des Moines river and Miller creek around the borders of which the stone outcrops. The overburden is probably not more than ten or twelve feet at any place, and an unlimited supply is thus available.

At Dudley large quantities of rock have been removed just west of the Chicago, Burlington and Quincy station, both north and south of the tracks. Stone is now quarried by Andrew Lames on the south side of the railroad. The following strata are shown in the quarry face:

		FEET.
5.	Loess-like silt, underlain with a thin bed of iron-stained gravel	18
4.	Bluish shale in places.	
3.	Limestone, compact but shatters readily on exposure, separates in 2 to 3 inch laminæ	2½
2.	Limestone, compact, light brown to blue, fossiliferous in upper portion, and contains much iron pyrites	9½
1.	Blue limestone in thin layers	18-20

Only number 2 is used for building purposes and it furnishes good dimension stone, although not so heavy as the corresponding layer in the Eddyville section. Much crushed stone is produced, the Railroad Company using the major portion of the output. All work in the quarry is by hand. Stone for the crusher is loaded on small flat cars and drawn by one horse. Stripping is done by means of scrapers.

The T. L. Stevens opening is located on Middle Avery creek one-half mile south of Dudley. The same strata are to be seen as given in the section above. They are covered with loess and gravel. The iron sulphide concretions are more conspicuous and numerous than in the Lames section.

The Saint Louis beds in this vicinity afford a fair grade of crushed stone for ballast. The presence of iron pyrite, which rapidly weathers and leaves blotches, streaks of iron rust, and small cavities in the stone, is a drawback to the extensive use of number 2, which is otherwise suitable for building purposes.

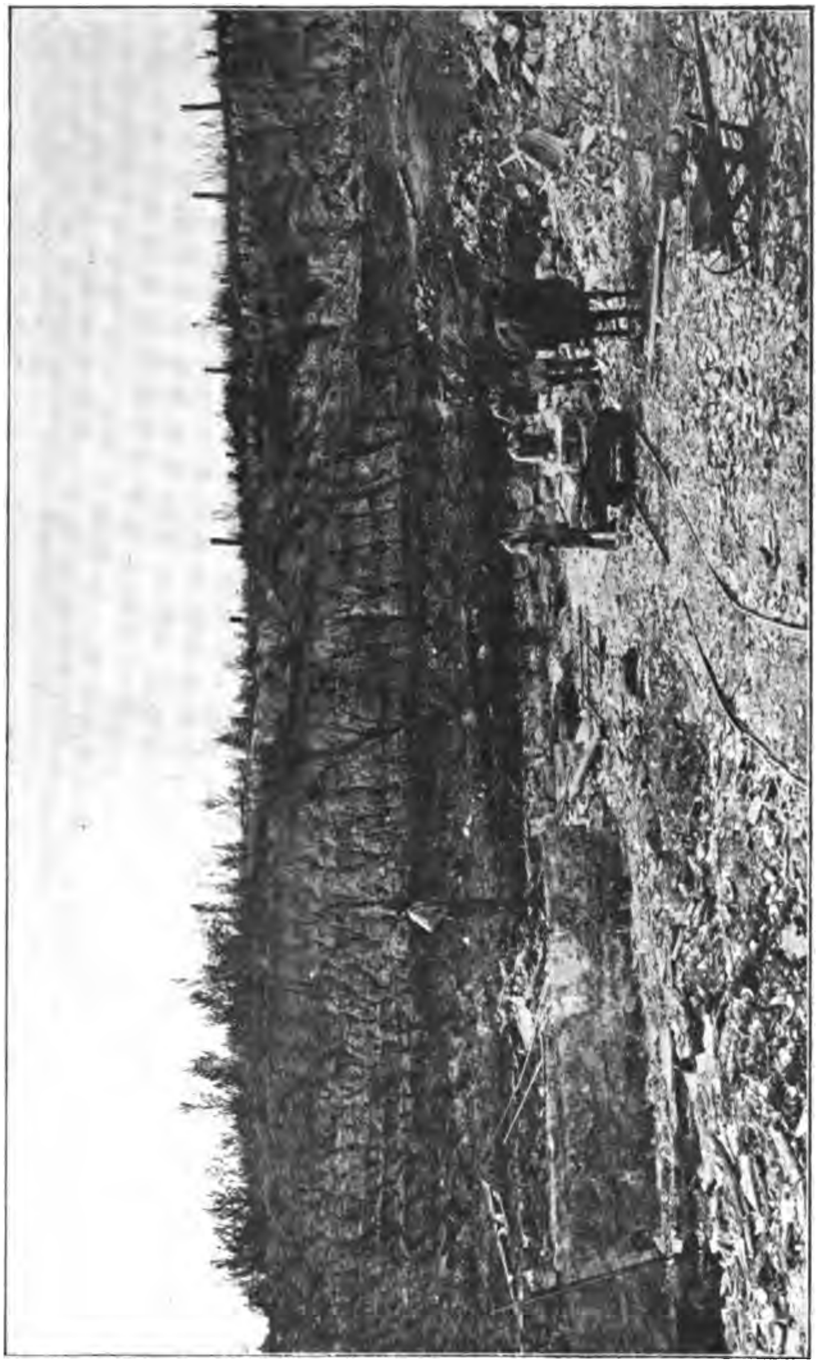

PLATE LVIII—Andrew Lames quarry, Dudley, Wapello county, Iowa.

Without question there is more and better stone available in the vicinity of Eddyville than at Dudley, but it is in a less accessible location at present for railroad transportation.

Limestone has been quarried at several points in Ottumwa and vicinity. It has for many years been taken from the bed of the river at Ottumwa during low water. A new place is opened up and worked out each season. That portion of the bed of the stream which is to be quarried during the summer is enclosed by an embankment to keep out the water. This is constructed of barrels filled with clay against which are piled broken stone, gravel and sand, until a substantial barrier is built up. About six feet of limestone are removed, the upper layers being thin-bedded and the lower ledges three to eight inches thick.

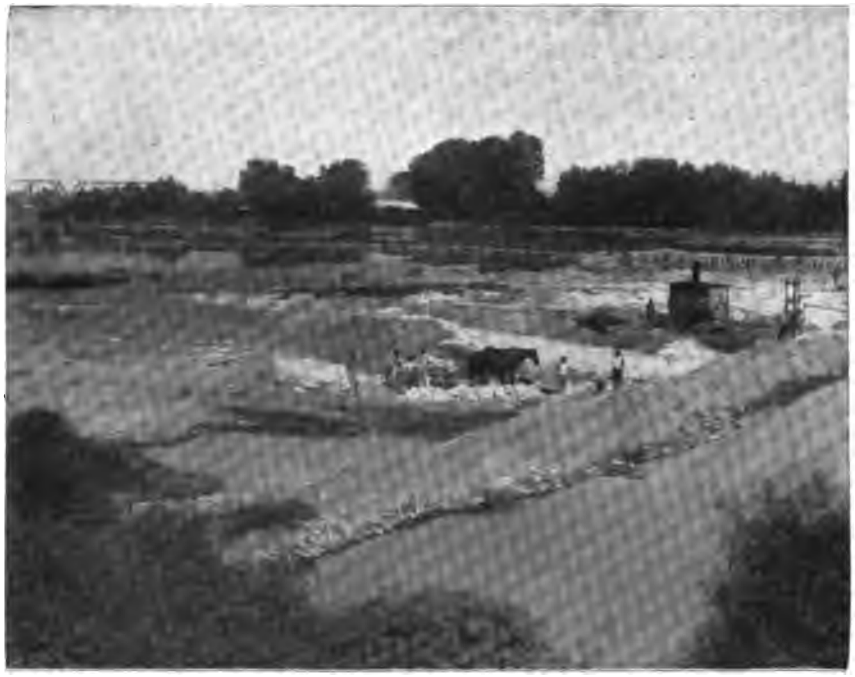

FIG. 37 — Quarry in bed of the Des Moines river at Ottumwa.

WASHINGTON COUNTY.

The Saint Louis limestone occurs over a large area in the southern portion of the county, comprising a strip ranging from about five miles in width, on the east boundary, to eleven miles on the west. The most important exposures occur along the Skunk river and near vicinity, in Brighton and Clay townships. The principal quarries are located in the immediate vicinity of the town of Brighton. The most valuable ledges quarried here, as well as at other points, belong to the upper member or Pella beds. The overburden is usually heavy, ranging from a few feet at the face in natural outcrops to fifteen or twenty feet a short distance toward the bluffs. There are two main ledges especially suitable for bridge stone which range from sixteen inches to two feet in thickness and rest upon two layers of flagstone. The flagstone layers are in turn underlain by heavy beds which were at one time worked by the Chicago, Rock Island and Pacific Railway Company near Brighton. These lower ledges are more or less water-coursed, and the quarry has been abandoned. On the west side of the Rock Island tracks, immediately north of town, the following layers were formerly exposed and quarried:

		FEET.
7.	Soil and drift, variable, thickening rapidly in the bluff	5-15
6.	Marl	2-4
5.	Limestone, in thin layers	$\frac{3}{4}$
4.	Limestone ledge, bridge stone	$1\frac{3}{4}$
3.	Limestone ledge, bridge stone	$1\frac{11}{12}$
2.	Limestone, flagging and rubble	$\frac{1}{2}$
1.	Limestone, flagging and rubble	$\frac{1}{2}$

Other quarries opened in the immediate neighborhood show essentially the same beds but in slightly different thicknesses.

About two miles northwest of Brighton, a quarry is being operated on the Whitmore place. The beds developed are as follows:

		FEET.
2.	Loess and drift up to	20
1.	Limestone, gray-blue, compact, tough, somewhat fossiliferous; in ledges as follows: Top ledge, 8 inches. Bridge stone, 20 inches. Bridge stone, 20 inches. Flagstone, 6 inches. Flagstone, 6 inches.	5

The upper ledges are very much weathered along the joint planes, and in places the blocks are reduced to rounded cores practically valueless though they appear to be as tough and of the same color as the unweathered blocks. The ledges work readily by the feather and wedge method. The flags are somewhat rough but appear to be durable.

The Chicago, Rock Island and Pacific Railway has used much of the stone of the district for bridge purposes. The stone has been generally used in the town and county and has been shipped in large quantities to adjoining counties.

The stone quarried in this region is fine-grained, compact, breaks with an even to conchoidal fracture, and is of a pleasing ash-gray color. It is of good quality, but limited in quantity, as only a few ledges are workable, and can be obtained only at great expense on account of the excessive overburden. Below are the disturbed beds of the Verdi which are of little value for quarry purposes. Small quarries have been opened in these beds near Verdi, but have long since been abandoned.

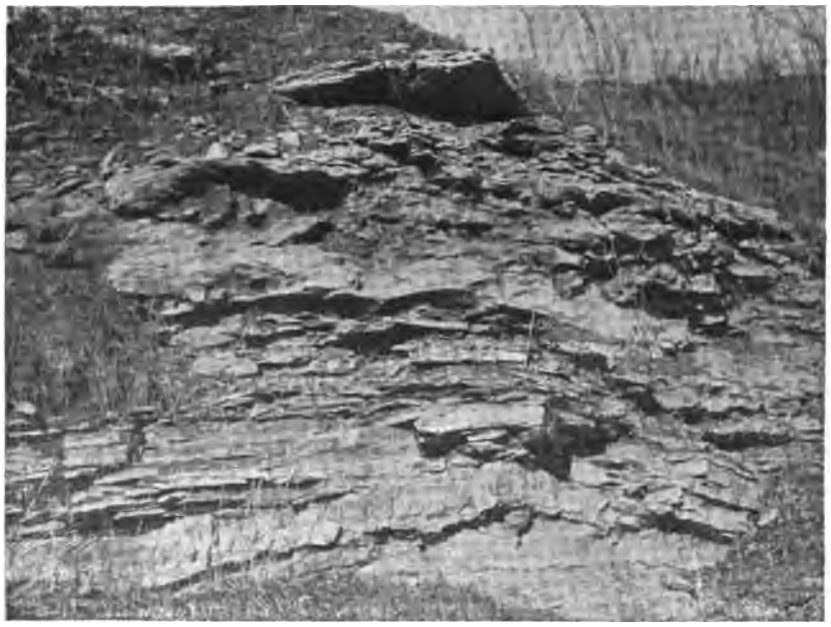

FIG. 38 — Irregular beds of limestone in the Saint Louis, Verdi quarry, Washington county.

About three miles south of Washington on Crooked creek, a small quarry has developed the lower magnesian portion of the Saint Louis, but is of local importance only.

WEBSTER COUNTY.

In Webster county the outcrops of the Saint Louis limestone worthy of mention are confined to the Des Moines river and immediate tributaries, from the north line of the county to Fort Dodge. A few detached areas are known south of this point along the river, and one or two small patches occur in the interior of the county. The beds comprising the Saint Louis are decidedly heterogeneous in character, varying from a hard, compact limestone in well developed ledges to a structureless, clayey marl, and from a pure calcium carbonate to a highly magnesian limestone. In places a calcareous sandstone appears. The beds are usually too deeply buried under the Coal Measures and glacial debris to be of interest economically, but in the vicinity of Fort Dodge and northward along the river and along Soldier creek, considerable areas have been partially stripped of their overburden and quarrying made possible. On account of the lack of persistence and rather indifferent quality of the beds, quarrying has not been, and is not likely to become, an important industry in the county. The stone has been developed at a number of points, and a considerable quantity has been used for foundations and retaining walls in and about Fort Dodge. A few representative sections are given herewith.

Section at Miller's quarry, near the stone bridge over Soldier creek in Fort Dodge:

		FEET.
7.	Soil	2
6.	Gravel, fresh, cross-bedded	10
5.	Clay, yellow, not jointed, unleached, many limestone pebbles	15
4.	Soil and clay mingled, both unleached, soil dark and containing many wood fragments	15
3.	Sand, uncemented, containing lumps of coal and large pieces of wood, in layers varying greatly in color from white to gray	8
2.	Calcareous sandstone, a single layer, very firm	1½
1.	Limestone, layers coarse, often two feet thick, stone of fine, even texture, no fossils	25

In the creek bed at the foot of this exposure the limestone gives place again to calcareous sandstone, the thickness of which could not be determined.

Number 1 in the above section is variable, the beds ranging from limestone more or less pure, to limestone more or less magnesian. The texture also lacks constancy. The terrace on the west side of the river from the mouth of Lizard creek northward for about two miles is supported by the Saint Louis limestone. South of the center of section 7 in Cooper township, a good section may be viewed. The beds are as follows:

		FEET.
5.	Sand and silt	5
4.	Limestone, rather heavy-bedded, variable, with persistent chert band near the top	12
3.	Sandstone, cherty in places	½
2.	Limestone ledge	1½
1.	Sandstone, to water level	1½

While the limestones continue to the county line, they are as a rule too deeply covered and too far removed from transportation lines, to merit consideration. Below Fort Dodge limestone outcrops are unimportant.

PENNSYLVANIAN SERIES.

The Des Moines.

The Lower Coal Measures are not important in the production of quarry products. They consist essentially of shales, shaly sandstones, sandstones and occasional thin bands of limestones. The sandstones, as a rule, are poorly indurated and not of pleasing color. Occasionally they are sufficiently cemented to be used for foundations of unimportant structures and for other rough masonry. Such deposits usually assume a lenticular form and are exceedingly variable in texture, color and state of induration both horizontally and vertically. The most important lenses occur in Marion, Jasper, Wapello, Boone and Webster counties. The Red Rock sandstone represents, perhaps, one of the best known examples and is described later. The best examples of the possibilities and also of the limitations of this stone may be seen in some of the residences along West Grand Avenue in the city of Des Moines. Less extensive deposits appear in the Coal

Measure outliers in Johnson county, where the stone was used in some of the oldest buildings of the district.

The limestones are usually more or less argillaceous and have not proven satisfactory as a quarry stone. The best examples may be seen in Appanoose county. These limestones also afford material suitable for the manufacture of lime and have been so used to a limited extent.

APPANOOSE COUNTY.

The Des Moines stage of the Upper Carboniferous underlies the whole of Appanoose county, and consists of shales with several well defined limestone horizons of small thickness. The principal limestone beds are known as the "float rock," which varies from two to four feet in thickness; the "fifty-foot" limestone, ranging from four to ten feet; the "seventeen-foot limestone," or "little rock," running from one to three feet; the "cap rock," showing from two to four feet; and finally the "bottom rock," which attains a thickness of more than three feet. One or more of these beds are exposed at numerous points along the various streamways, and oftentimes are fairly accessible. All are essentially non-magnesian, reasonably pure, and occur in moderately thick beds. They resist the weather as well as the average limestone, but on account of their limited occurrences, will never lead to the establishment of an important quarry industry. Some quarrying has been done in the vicinity of Centerville, Milledgeville, and Mystic, mainly from the "fifty-foot limestone." Lime of good quality has been burned from the same horizon, but both industries have been extinct for some years.

The Chariton conglomerate has been exploited in a very small way in the vicinity of Moravia, but the openings have long since been abandoned, and promise nothing for the future.

DALLAS COUNTY.

The Coal Measures underlie the entire county, and are made up of a series of shales, sandstones, and occasional thin limestones and thin seams of coal. The shales greatly predominate. Good sections are exposed along all of the principal streams.

The sandstones occur in lenses, and are best exposed along the Raccoon river. The most important lenses occur in the vicinity of Redfield. As a rule the sandstones are not well indurated, and are of a reddish brown color. At a few points, well indurated beds are available, and have been quarried intermittently for more than a quarter of a century. The most important quarry sections are given below.

Section exposed on the southeast quarter of section 3, Union township, about two miles southeast of Redfield:

		FEET.
5.	Drift, of variable thickness.	
4.	Sandstone, soft, buff, heavily bedded	8
3.	Sandstone, blue, compact, hard	7
2.	Clay-shales, sandy, blue	4
1.	Sandstone, exposed to river	8

Number 3 is the only rock quarried. At the quarry it has a thickness of seven feet, but it thins out rapidly, and about thirty rods east, it is only one foot thick. The stone is of excellent quality, and is scarcely affected by weathering agencies. It was used extensively in Redfield, and was shipped to Fonda, Waukee, and other points on the Spirit Lake branch of the Chicago, Milwaukee and St. Paul Railway.

The sandstones have been quarried at other points, notably near the mouth of Bulger creek, where a nine foot ledge of hard, well indurated sandstone appears. At the present time, sandstone is not used, save locally, and then in a very small way.

The limestone bands make up a very small part of the Coal Measure section, and as a rule, possess no commercial value. One exception may be mentioned, where the limestone has been quarried quite extensively. The section is given below.

Talbot quarry, located on the southwest quarter of section 29, Linn township, about four miles northwest of Redfield:

		FEET.
11.	Soil and drift	3
10.	Clay, sandy, buff	8
9.	Shale, black, fossiliferous	2
8.	Coal, with clay parting	1½
7.	Fire clay	3
6.	Shale, gray, with lime concretions	4
5.	Limestone, hard, compact, blue, fossiliferous above, mostly in solid ledges	7

		FEET.
4.	Shale, light gray	21
3.	Limestone, gray, brecciated above	1½
2.	Shales, gray, not fully exposed	1½
1.	Shale, black, fissile, coaly below	1½

DAVIS COUNTY.

The streams which traverse Davis county are small and have accomplished little towards exposing the rock strata which underlie it. A few feet of the Coal Measures are to be seen in the valley of Soap creek, whose course is entirely across the north edge of the county. Coal Measure sandstone beds belonging to the Des Moines stage of the Upper Carboniferous appear at water level at intervals along this stream in the vicinity of Carbon where it is locally used for foundation material. It is of no value for fine work but constitutes, so far as is known, the sole building stone resource of Davis county.

GUTHRIE COUNTY.

The Des Moines strata furnish some sandstone and limestone that are found of service locally in the eastern part of Guthrie county. A gray sandstone belonging to the Coal Measures has been quarried on a small scale at Panora. The usable beds of this stage are thin and so associated with argillaceous strata that they are very seldom worked for building stone alone.

HARDIN COUNTY.

In Hardin county the Coal Measures are represented by an upper heavy-bedded, ferruginous sandstone which often presents conglomeratic to concretionary facies and is cross-bedded throughout; and by a lower shale which carries some coal and often contains highly calcareous, fossiliferous ledges. The main body of the sandstone is dissected by the Iowa river, which forms a gorge extending from Xenia to Steamboat Rock. The sandstone reaches its maximum development in the vicinity of Eldora where it attains a thickness of eighty feet. The Eldora section is as follows:

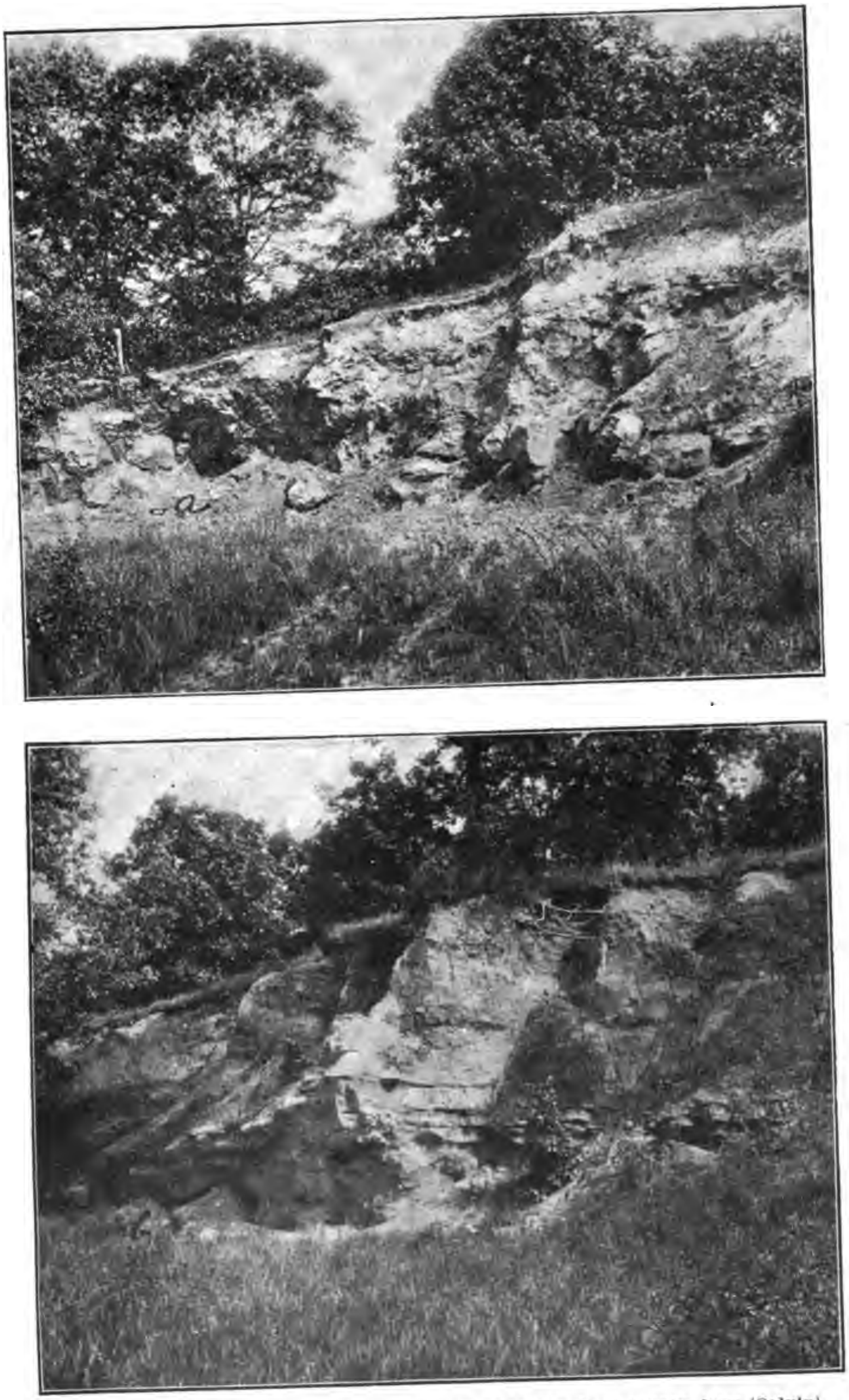

PLATE LIX—Des Moines Sandstone quarries west of Amana, Iowa county, Iowa (Calvin).

ELDORA SECTION.

		FEET.
7.	Drift (on the face of the scarp)	0-3
6.	Sandstone, weathered and shattered; ferruginous, conglomeratic and concretionary; quartz pebbles ranging up to a third of an inch are common. False bedded throughout; some fossil wood fragments present	40
5.	Sandstone, heavy-bedded	10
4.	Talus slope	20
3.	Shale, carbonaceous	1
2.	Shale, light colored above and variegated below	20
1.	Kinderhook limestone (top about ten feet above the water level)	6

The Eldora sandstone has been used to a certain extent in the foundations of numerous structures in and about Steamboat Rock, Eldora and Xenia, but at the present time none of the quarries are operated, save intermittently and then only on a small scale. The stone is extremely variable in texture, structure, and state of induration, and these factors, taken with its dark red-brown to yellow-brown color, make it certain that it never will be popular as a structural material. Vast quantities are available and easily accessible, and when the stone is carefully selected it gives good service in the less imposing structures. Its use might be safely and profitably extended in backing walls faced with more expensive materials.

IOWA COUNTY.

Small Coal Measure outliers occur in Iowa county, the most conspicuous member of which is the usual variable sandstone. Several decades ago these beds were developed quite extensively by the several villages belonging to the Amana Society. Some of the oldest and most important buildings in these communities were constructed of these variable sandstones. The Amana store and the Amana church were built in 1862 and 1863 respectively, using the local stone, and both are in good repair. The store front was built of a red-brown sandstone obtained from a quarry about one and a half miles north of town, while a yellow-brown sandstone, said to have been obtained from a quarry equally distant northwest of town, was used in the sides and back walls. Other quarries were developed to the eastward and westward of these and used in the construction of the older buildings.

While some stone has been produced and used of late years for foundations and rough masonry purposes, no stone buildings have been constructed of the local material during the past quarter of a century. At the present time the old openings are much obscured by talus slopes. The stone available is very similar to that exposed in other border counties belonging to the same horizon. It is a sandstone, highly variable in color, texture, structure and state of induration. The prevailing colors are shades of yellow and brown combined with red; yellowish and reddish brown predominating. Texturally the stone is usually fine to medium grained, but occasionally shows a conglomeratic facies. Structurally the stone varies from a thinly bedded sandstone, with bedding planes fairly well defined, to a massive and imperfectly bedded deposit. False bedding is oftentimes very evident. As a rule it is imperfectly indurated, but appears to harden considerably on exposure. It varies from a very friable to a fairly compact stone. The deeper colored stone is usually the more highly indurated. The durability is sufficiently attested in the well-preserved buildings, where it has been exposed to the elements for almost half a century. As in the case of other Coal Measure sandstones, its color is not pleasing and its other properties are not sufficiently constant to commend it to the public. In quarrying the stripping increases rapidly from the natural outcrops and the percentage of usable stone is small, both of which factors contribute to the expense of production. While this variable sandstone has served a useful purpose in the early history of the communities, it has been displaced almost wholly by stone from other points, notably Stone City, which can be more cheaply quarried.

JASPER COUNTY.

All of the Paleozoic rocks exposed in Jasper county belong to the Des Moines stage of the Upper Carboniferous series. They cover the entire county, with the exception of a small triangular area of Kinderhook in the extreme northeast corner, and consist of interstratified shales, sandstones, coal and occasional thin beds of limestone. However, their character varies rapidly from place to place. The shales are prevailingly sandy and grade laterally into argillaceous sandstones. The sandstone layers are in places calcareous and, especially in connection with certain coal seams, pass into arenaceous limestones. Limestones of the darker colored variety occur as lenses and concretionary masses in some of the coal basins.

In Jasper county the rocks of the Des Moines stage are almost universally covered with drift. Exposures are not numerous, as a rule, but are found fairly well distributed over the southern half of the county. Although the best sections are to be observed along stream ways, natural outcrops are not lacking over the uplands away from the streams.

Sandstone from the coal-bearing strata has been quarried at three known localities: section 34, Des Moines township; in a railroad cut in section 30, Fairview; and two miles above Lynnville, in the valley of North Skunk river. At the latter place only is quarrying at present carried on in the county. The exact location is the northeast quarter of the northeast quarter of section 34, Richland township. The quarry section at this point is as follows:

		FEET.
5.	Weathered shale	5
4.	White sandstone, soft, grading downwards into pink, brown and red	5½
3.	Plastic, white clay	⅝
2.	Sandstone, red to brown, compact; containing many small cavities lined with plastic clay, or containing pulverulent, red ocher. Micaceous, with fossil lepidodendrons	15
1.	Carbonaceous shale	1½

The total thickness of salable stone is in number 2, fifteen feet. It is evident that considerable stripping of the overlying shales is required. The quarry is worked by William Northcutt. Three hundred perches per year is the output. The stone is durable, and supplies the local demand for cellar and foundation walls.

RED ROCK SANDSTONE.

This formation is included in the Des Moines stage of the Upper Carboniferous, but it may be differentiated from the Coal Measures proper because of its uniformity, and the somewhat unique relation which it appears to bear to the other members of the series. In Jasper county it occupies a narrow elongated area coinciding in direction and corresponding in width with the territory covered by it in Marion county. The general trend is northeast-southwest, and in width it averages two and one-half to three miles, tapering to the northward.

Outcrops of this rock are to be seen at various points near Reasnor, on both sides of the Skunk river; along Buck creek; on Elk creek near Murphy; along North Skunk river in the vicinity of Kellogg; and on Rock creek in sections 9, 16 and 17 of Rock Creek township.

Quarrying has been done at several points in the county in the belt of Red Rock sandstone, which affords the only extensive deposits of building stone in the county.

In section 17, Rock Creek township, the old Morgan quarry, on the land of G. M. Henning, was opened over forty years ago. A face twelve feet in height is exposed, consisting of a heavy bed of brown stone separated by two feet of shattered rock from a four foot stratum of compact, reddish-brown sandstone. Similar strata have been worked both above and below this quarry in the valley of Rock creek and its branches.

One mile east of Kellogg the brown sandstone has been quarried quite extensively in the past by the Chicago, Rock Island and Pacific Railroad Company. Fifteen feet of the sandstone are open to view. Large plans appear to have been made here for the development of these quarries, but no work has been done for years.

On the hill slope a short distance north of the town of Reasnor, fourteen feet of the sandstone may be observed in a small quarry; the prevailing color is brown, approaching a red in places. The sand grains are at times so coarse and irregular in size as to give the rock a finely conglomeratic texture. Many of the largest grains are of a jaspery nature, and some, approaching a pebble in size, appear to be fragments of an earlier sandstone. Cross-bedding is not uncommon. The base of this exposure is about sixty feet above the flood plain. In detail, this section is as follows:

		FEET.
7.	Loess, becoming fine sand on the hill-top	4
6.	Buff sandstone, micaceous	½
5.	Brown sandstone, cross-bedded	2
4.	Heavy-bedded sandstone, conglomeratic	2½
3.	Laminated, red and gray sandstone, cross-bedded	1½
2.	Heavy bed of brown sandstone, containing ferruginous, sometimes hollow nodules	4½
1.	Like No. 2, to base of quarry	3

In the northwest quarter of section 21, Buena Vista township, on Elk creek, there is exposed in two small quarries a maximum thickness of twenty-two feet of the sandstone. It exhibits the same characters as in former sections as to bedding and color. Some of the red is to be seen but the brown variety prevails. In the Lanphear quarry the jaspery, quartzitic bands are quite pronounced, as are also the spheroidal nodules. The latter frequently consist of concentric, ferruginous shells between which sandstone is intercalated. The greatest thickness of beds is found in the old Dooley quarry, where the ferruginous bands appear as firm crusts of siliceous limonite, separating the major beds of the section. The rock is coarse in texture, friable, and varies in color from gray to deep red. All the layers seem to be thoroughly impregnated with iron oxide.

One mile south of Reasnor, at "Stony Point," the brown sandstone has been quarried in the past.

The most extensive quarrying operations in the county were formerly carried on at the old Kemper quarry in section 8, Fairview township. The rock was quite widely known as the Monroe red sandstone, although both red and brown stone were taken out. John Reinhart took stone from here forty years ago, and worked the quarry for twenty-five years. E. G. Kemper produced, in seven or eight years of his possession, some cut and dressed stone, and at one time employed as many as twenty men. Considerable stone was shipped. The present owner, A. Herwehe, has put out very little stone in the last two years, although there is a fair demand locally.

Mr. B. L. Miller* has briefly described this quarry exposure as follows:

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* Geology of Marion county, Ann. Rep. Iowa Geol. Surv., Vol. XI, p. 159, 1900.

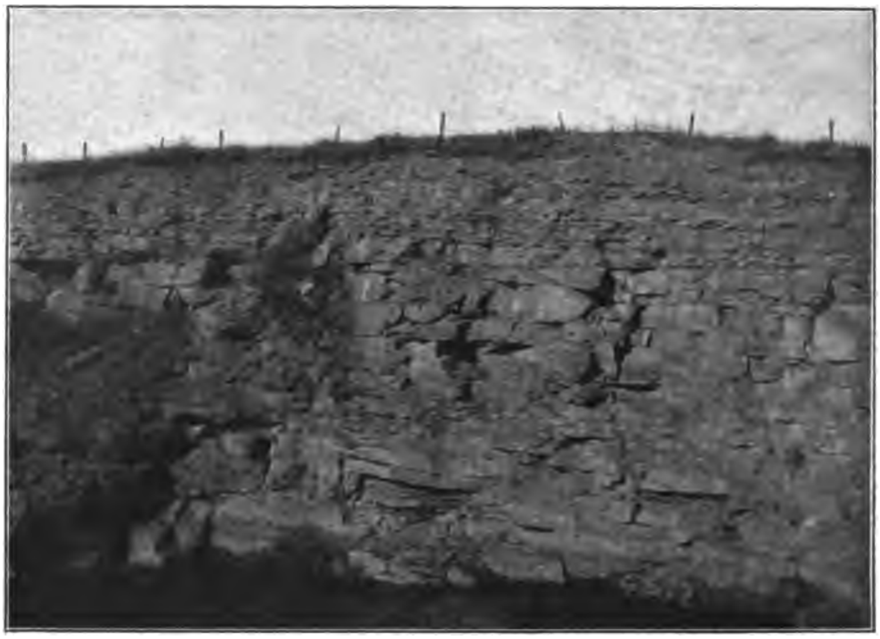

FIG. 89—Herwehe quarry in Red Rock Sandstone. Northwest quarter of section 8, Fairview township, Jasper county, cross-bedding is conspicuous throughout the section.

	FEET.
4. Soil	1
3. Weathered, brown sandstone	9
2. Heavy beds, yellow-gray, variegated	10
1. Dark red sandstone, heavy bedded	8

Two small quarries are opened here and both the brown and the red stone have been taken out. Cross-bedding is very conspicuous in the upper part of the section. The change in color is gradual from the top downwards, and appears to be due to the degree of leaching and hydration which the rock has undergone. Chemical tests of the brown sandstone show a loss on ignition of 3.8 per cent, and 16.27 per cent of iron and aluminum oxides. The dark variety pulverizes to a deep red and ocherous powder, and analyzes 31.5 per cent Fe_2O_3. At one point in section 21 of Fairview township a weathered outcrop of the red stone occurs from which the resulting ocherous iron oxide has been taken for mineral paint. In places in both the red and brown sandstone, bands or nodules of a dense, flinty character occur, which appear to be quartzitic in nature and origin.

The following description of the sandstone points out its chief characteristics:[*]

"It is a moderately coarse-grained stone, with some range of color and texture and corresponds in general with the Red Rock stone which has been more widely marketed . . . As will be seen from the tests, it is an excellent stone and might be used to advantage in all structures similar to those in which brown stone has been used so extensively in the east. Under the microscope it seems to be made up of rather coarse and rounded grains of quartz cemented by a matrix of red-brown, iron-stained material which, judging from the analysis, is largely ferric oxides, but contains also some aluminous material. The sand grains are rarely in contact; the interstitial areas being usually as large as the cross-section of the individual grains."

The chemical analysis of this stone as given on page 412 of Dr. Bain's paper, is as follows:

SiO_2	84.35	per cent.
Al_2O_3	8.62	" "
$FeO+Fe_2O_3$	5.59	" "
CaO	.88	" "
H_2O+loss	.43	" "

The Red Rock sandstone constitutes the most important source of building stone in the county. There are unlimited quantities available and it merits a much wider use than it has at present.

LUCAS COUNTY.

The country rock of Lucas county belongs entirely to the Coal Measures. The formation consists almost wholly of shales with seams of coal and accompanying beds of fire clay. Occasional thin bands of dark bluish limestone and moderate thicknesses of sandstone are found associated with the heavy beds of shale.

In Pleasant township, near the northeast corner of the county, ten to fifteen feet of a coarse, grayish blue sandstone outcrop along Flint creek. Quarrying to any extent has not been done, but the beds are available at a number of points along this stream and its tributaries. On a branch of the Little White-breast in the northeast quarter of section 32, English township, a soft yellow sandstone occurs associated with bituminous shales and has been quarried in years past.

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[*] H. F. Bain: Ann. Rep. Iowa Geol. Surv., Vol. VIII, p. 398.

Upper Coal Measure beds may be seen on Long Branch in the northwest quarter of section 3 of English township, where limestone quarries were formerly worked. The beds consist of about four feet of light gray overlain with buff limestone, separated in ledges by calcareous shaly partings. The stone is said to produce a high grade of quick-lime and has been used for this purpose. Limestone has also been quarried and burned for lime on the Little Whitebreast two miles northeast of Chariton.

On the whole, the building stone resources of Lucas county are very limited, the valuable beds being in general so associated with other sedimentary strata as to render their utilization impossible.

MARION COUNTY.

Extensive beds of sandstone occur in the Coal Measures of Marion county. The most important deposits are found in the vicinity of Red Rock along the Des Moines river. One-half mile northwest of the town a large quarry has been opened, the main face of which is thirty to forty rods in length. There is a maximum thickness of 100 feet of beds here exposed. The stone was channeled, by which method of quarrying blocks of almost any desired dimensions were obtainable. The sandstone separates in ledges five to six feet in thickness. Quarrying operations were formerly carried on here on an extensive scale. A switch was connected with the Wabash at Cordova and the product was shipped to points along this line from Des Moines to St. Louis. The quarries have been worked only intermittently during the past ten years and are now practically abandoned.

The sandstone appears to form an elongated lens about ten miles in length and three miles wide. The longer diameter of the lens extends in a northeast-southwest direction. From the maximum thickness of over 100 feet attained by the beds, they thin rapidly. The higher portions of the sandstone ridge have a light overburden of loess, but this attains considerable thickness on either flank. The rock is massive and the heavy beds are practically free from joint planes. The sandstone is imperfectly indurated, varying in hardness from exceedingly friable to almost quartzitic. The color is also variable, ranging from almost white or pale yellow to deep shades of red and brown. In some of the beds the coloring matter is irregularly distributed producing a blotchy or mottled effect. The prevailing cements are the oxides of iron and silica, although the upper beds are somewhat calcareous. While predominantly soft, the Red Rock stone resists weathering well and may be rated as fairly durable.

MARSHALL COUNTY.

The Coal Measures in Marshall county consist chiefly of shales with occasional beds of sandstone. A heavy bed of sandstone appears in Timber Creek township, and has been developed to a limited extent. Quarries have been opened on sections 8 and 9, and stone suitable for the rougher grades of masonry has been produced. The sandstone is reddish brown in color, and apparently durable. It exhibits a conglomerate facies in part. Well polished grains of sand and gravel are laid in a matrix of ferric oxide. Some of the iron oxide is found in the form of small nodules which frequently are hollow and possess the concentric structure peculiar to concretions. The impressions of trunks and branches of trees which have retained their woody texture in a remarkable degree, although their original organic substance has been entirely replaced by mineral matter, occur throughout the beds. In some instances, a pulverulent ash surrounded by a highly ferruginous shield is all that remains. One case exhibited a central core of very hard material, almost quartzitic, around which was a zone of wood fibre, and surrounding all, a concentric, ferruginous shield. All of the stems are in a recumbent position.

At the present time only the upper layers have been exploited. The lower beds are more regular and afford a stone suitable for building and trimming.

MUSCATINE COUNTY.

The Des Moines stage of the Coal Measures occurs in a narrow outlier along the Mississippi river about five miles in width and extending from Scott county to a point about three miles west of the city of Muscatine. The beds which represent the Des Moines are largely mechanically deposited sediments, ranging from coarse conglomerates to fine shales and fire clays, with unimportant seams of argillaceous limestone and coal. The sandstones constitute the most important beds and occur in rather thick lenses. They are variable in texture, coloration and state of induration. On account of their inconstancy they are not as highly prized for structural purposes as might otherwise be the case. They have been used quite extensively in the past for foundations, retaining walls, and other structural purposes. At the present time, but little sandstone is being quarried in the county. The principal quarries are located on the West branch of Pine creek in Montpelier township, on section 21 in the river bluff in Sweetland township, and on Lowes river in section 32, Bloomington township. The quarry stone attains a thickness of sixty feet in the first quarry, is in heavy beds up to four feet in thickness, is rather fine grained, and is characterized by peculiar, wavy, ferruginous bands, probably due to infiltration of iron.

In the second quarry, the beds are a little coarser in texture, but otherwise similar to those in the first, while those quarried on Lowes river are less ferruginous and as a consequence, lighter in color, with occasional darker layers.

POLK COUNTY.

The Coal Measures as developed in Polk county comprise shales, argillaceous limestone, sandstone and occasional coal seams. The argillaceous deposits greatly predominate. The sandstones are usually imperfectly indurated, while the limestones occur only in thin beds or as "Cap-rock," and neither affords any considerable amount of material suitable for structural purposes. The sandstones have been quarried to some extent but are not used in important structures. The sandstone beds exposed at the foot of Capitol Hill have probably been more extensively developed than any other in the county and are said to have supplied material for the walls of old Fort Des Moines. The beds are exceedingly variable in color, texture and hardness and are easily accessible. The county must depend upon other sources for structural materials.

WAYNE COUNTY.

Exposures of the underlying rocks are very scarce in Wayne county. The Des Moines stage of the Coal Measures occupies the major portion of its area. Stone suitable for quarrying is known to occur only along the south fork of the Chariton river near the east edge of the county. A small amount of rock has been taken out on the farm of Mr. Talkington in the northeast quarter of the southwest quarter of section 36, Wright township. Four feet of gray fossiliferous limestone are exposed, overlain with fifteen to twenty feet of drift. The stone is traversed by veinlets of calcite and separates into thin laminæ on exposure. The same bed has been worked at a few points farther up the river and over the line in Appanoose county. It can be of little importance except locally.

WEBSTER COUNTY.

The Des Moines river and its immediate tributaries have exposed heavy beds of sandstone at several points in the county. As a rule these beds are composed of massive, friable sandstone oftentimes strongly pyritic or marcasitic. The presence of these ingredients causes the stone to disintegrate rapidly on exposure while their presence in small quantity in a finely divided state produces discoloration of the exposed surface.

Several quarries have been opened and operated at various times. The most important one is located in the northwest quarter of the northeast quarter of section 14, township 88 north, range XXVIII west. The quarry is located in a small ravine where the rock is naturally exposed. An average section through the quarry face shows the following beds:

		FEET.
3.	Soil and drift	10-15
2.	Shale	2-3
1.	Sandstone	15

The sandstone is probably much thicker, but it has not been quarried below the bottom of the ravine. It is ferruginous and contains many selenite scales which look like mica. Even in a given layer the stone varies often in color and hardness. The colors are various shades of red. Some layers are practically useless for building purposes because they contain many small iron concretions. At certain points in the quarry the rock attains a fair degree of hardness. The layers are of a desirable thickness, varying from six inches to two feet. Jointing is imperfect, but sufficiently well developed to render quarrying easy. Some years ago the quarry was well equipped with steam derricks, and a side track gave good shipping facilities, but at present it is not operated. The product is known commercially as the Albee sandstone, and at one time this was the most extensive sandstone quarry in the state.

Sandstone quarries have been opened at other points in the county. In Fort Dodge some stone of fair quality has been taken out. North of the city the sandstone layers appear to be better cemented but have not been developed to any extent.

The Missouri.

The Missouri stage of the Upper Carboniferous is made up largely of off-shore deposits in which shales greatly predominate. Interbedded with the shales are a series of thin limestone layers varying from a few inches to twenty or even thirty feet in thickness, and persistent over considerable areas in the southwestern portion of the state. These limestones are usually quite free from such impurities as magnesia and pyrite, but they often display a decided tendency to become argillaceous. The ledges constituting the more important limestone zones are usually separated by clay partings, varying from a fraction of an inch to a few inches in thickness. The most important horizons belong to the Bethany sub-stage and are named after localities where they are typically exposed. From the base upwards the principal limestone members are as follows: 1, the Fragmental limestone, typically developed at Bethany, Missouri; 2, the Earlham limestone; 3, the Winterset limestone; 4, the DeKalb limestone; and 5, the Westerville limestone, from the town of the same name in Union county.

A sixth limestone horizon far above the strata of the Bethany, may for present purposes be designated the Stennett limestone. It is typically developed at Stennett in Montgomery county, and is believed to be present in the adjoining counties. The second and third members are by far the most important and have been extensively developed at a number of points, notably at Earlham, Winterset and Peru in Madison county. The stone representing the different horizons varies considerably in weather-resisting properties but when properly selected, excellent material can be secured for all sorts of structural purposes.

ADAIR COUNTY.

Adair county is included within the area in which the Missouri strata are believed to be the country rock. Cretaceous beds probably overlie in part the Carboniferous rocks in the western part of the county but the all but universal concealment of the indurated strata by the loess and glacial bowlder clays renders accurate data difficult to secure. The shales and more calcareo-argillaceous beds of the Des Moines stage of this series are believed also to appear beneath the fragmental beds of the Bethany at a few points on Middle river, along which the only quarry operations known in the county are carried on.

A well marked limestone horizon with associated beds outcrops on Middle river and its small tributaries where it crosses the northeast corner of Brown township. Below Howe, in sections 11 and 12, on a small branch from the southwest, quite extensive quarrying has been done. The openings are on the land of Mr. W. P. Perry and stone has been taken out for over twenty years. The following section may be observed in the northwest corner of section 12, close to the confluence of the above tributary and Middle river:

		FEET.
10.	Soil, loess, and drift conglomerate containing Cretaceous materials	7
9.	Limestone, broken into blocks which are rounded by weathering and solution; buff in color, fossiliferous, narrow band of chert in residual clay, both above and below	1⅙
8.	Limestone like No. 9 with two inch cherty clay residue below..	½
7.	Limestone, firm ledge somewhat broken by weathering; marked tendency to separation into blocks by vertical joints	¾
6.	Shaly limestone, chert bearing, by weathering forms a reëntrant in the quarry face	1 1/12
5.	Forms limestone ledge, persistent	½
4.	Shaly limestone, blue to gray where unweathered, but ironstained at crop; persistent and forms a conspicuous reëntrant	1¼

		FEET.
3.	Limestone, light brown, compact; has tendency to dissolve along joints to form caverns. At its base is a heavy band of chert which in places is pulverulent and white	$\frac{7}{12}$
2.	Limestone, cavernous, with tendency to jointing, separated as a rule by thin shaly partings into three distinct ledges, 5, 10 and 9 inches in thickness	2¼
1.	Regularly bedded, compact, brown to bluish limestone in 6 inch to one foot ledges, commonly separated by thin, brown clay partings, contains occasional chert nodules near the top; highly fossiliferous throughout to base of exposure	5

Stone has been taken out along a quarry face four to five hundred feet in length, the work being apparently limited by the heavy stripping. The base of the present exposure is about fifteen feet above Middle river. The lowest bed rests on earthy and carbonaceous shales, the contact being marked by numerous springs and seeps.

The best stone comes from numbers 8 and 9 near the top and from the basal member of the section. Number 1 especially affords excellent dimension material of any desired thickness. The output of this and neighboring quarries is used to a large extent locally for foundations, and for this purpose it is also hauled to Stuart and Greenfield.

To the south of the branch, and but fifteen to twenty rods distant from the foregoing, the same layers are worked. The beds outcrop also west of the road in section 11, where some quarrying is done. To the eastward, along the south side of Middle river, the limestone forms a terrace which is not deeply covered and where any quantity of stone is available.

Stone is also quarried in the southwest quarter of this same section, on the farm of Mr. Jas. Chambers. In the main the beds can be correlated with those of the Perry quarry section although the overburden is not so great and would prove less of a hindrance to development.

The Missouri beds outcrop at rare but gradually increasing intervals southeastward along the Middle river to its exit into Madison county. They are quarried at a few points in Harrison township. At, and in the vicinity of the mill dam at Port Union, the following succession of strata can be made out:

		FEET.
12.	Shelly, fossiliferous limestone to be seen one-eighth mile above the dam in the hillside where rock has been quarried.	?
11.	Firm ledges, good building limestone, to be seen at same place	3-4
10.	Limestone breccia, containing angular pieces of compact limestone of a maximum size of 2 to 3 inches; there are occasional fragments of dark chert in a soft limestone matrix. Conspicuous in hillside 20 rods above site of dam	?
9.	Ocherous red and purplish weathered shale, in view	2½
8.	Shelly limestone	?
7.	Solid ledge compact, durable limestone forming a shelf over underlying shale, at south end of dam at level of water in pond	⅝
6.	Gray shale with nodules and streaks of hard limestone, cylindrical forms, apparently vegetal remains	1½
5.	Bluish limestone capped with thin layer composed almost entirely of well preserved brachiopod remains	½
4.	Dark blue, clean shale	2
3.	Brownish, cavernous limestone, not persistent	½
2.	Black, slaty shale	1½
1.	Shelly limestone, breaking into nodular flakes and lenses on exposure; in bed of stream below dam where it causes a low falls. Known in excavation for mill wheel to consist of two 12 inch layers	2

Below is a "gummy" clay or soapstone which is practically impenetrable to the churn drill.

At all points observed, these strata occur beneath great thicknesses of glacial deposits. The limestone members of the section have afforded building material but their exploitation is of necessity limited. The beds above the fragmental limestone, number 10, are said to be quarried for local use on the farm of Robert Murphy on Middle river near the east county line, and at other points in this vicinity.

The two sections given above appear to include the basal members of the Missouri and the upper strata of the Des Moines stage, if regarded alone on stratigraphic position and lithologic similarity. There seems little question that number 10 of the Port Union section represents the base of the Bethany and that the non-brecciated beds above are the equivalent of the Earlham limestone in Madison county.* The Fragmental limestone does not appear in the Perry section as a distinctly brecciated layer. In other respects, the lowest member here visible, No. 1, is its equivalent, and the underlying shales therefore belong to the Des Moines.

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*Geology of Madison county, Iowa Geological Survey, Vol. VII. page 511.

ADAMS COUNTY.

The country rock in Adams county is in general deeply concealed by the glacial deposits and outcrops at but a few points along the Middle and East Nodaway rivers. As in adjoining counties, the Missouri rocks consist largely of shales, which may become highly calcareous and even marly, interstratified with usually thin beds of limestone which are in some instances of a character and extent to be of value. Similar also to bordering counties, beds of otherwise valuable stone are so deeply buried that their utilization is out of the question.

The Upper Coal Measures outcrop at Carbon in Douglas township, where the Nodaway seam is mined. The "cap rock" is an eighteen inch ledge of firm limestone and appears near water in the river. It is quarried for local use here and at intervals along the stream to Mt. Etna in Washington township, but it is of little importance and is difficult to obtain.

Stone was formerly quarried at Corning in the banks of the East Nodaway. Limestone appears at a number of places in the bed of the river for a few miles southwest of the town. The abandoned French quarry is located south of the river in section 3, Jasper township. Talus obscures the old quarry face, but a few hundred feet to the north in the bottom and bank of the river, the following sequence may be made out:

		FEET.
5.	Drift	3
4.	Fine sand, iron-stained	4
3.	Shale, light blue, plastic	5+
2.	Limestone, hard, compact, gray in color, fossiliferous; breaks easily at right angles to bedding planes and apparently does not weather easily on exposure	2½
1.	Fossiliferous limestone, yellow, weathered, to water level	½

There is evidence that quarrying has been carried on here on a scale of some magnitude, and the Corning stone is known and has been distributed over not only Adams county, but adjacent territory as well. The limestone is of good quality, and while extensive development is of necessity restricted by the heavy stripping, it should rank locally as a valuable resource.

CASS COUNTY.

Cass county is as a rule heavily covered with loess and drift, and the indurated rocks appear at intervals only along the larger waterways in the southern part of the county. The Missouri strata are known to be overlain in part with the Dakota sands of the Cretaceous.

Stone was formerly taken out at the old Fox quarries on the south bank of the West Nodaway in the southeast quarter of section 36, Noble township, and just across the road in section 31 of Edna township. The beds in these quarries belong to the same horizon as those exposed near Grant and described under Montgomery county, although no accurate correlations of individual strata can be made. The following section is compiled in large part from the *Geology of Montgomery County:*[*]

		FEET.
13.	Soil and loess, heavy covering.	
12.	Broken limestone, shales and residual clay	2
11.	Greenish shale, iron-stained	4
10.	Limestone, light gray to buff, contains fossils; split by vertical joints into large blocks; two ledges separated by thin band of shaly limestone, upper ledge, 2 feet 3 inches, lower, 1 foot 4 inches	3 7/12
9.	Calcareous shale, fossiliferous	1
8.	Limestone, sub-crystalline, gray to brown, in ledges from 9 to 14 inches; where exposed for only a few years, this stone is badly shattered and intervening shaly bands separate it into many thin ledges	7 1/12
7.	Shale, calcareous	1/3
6.	Limestone, brownish, sub-crystalline to dull	1 1/12
5.	Shale, in part gray, bituminous in lower portion	1 1/3
4.	Limestone, dark gray, coarse textured	3/4
3.	Shale, buff to gray, fossiliferous	1 1/3
2.	Shale, variegated, lower part carbonaceous, micaceous, and splits into conchoidal fragments	2 1/3
1.	Limestone.	

At the present time, no quarrying is done at this point, and the lower members of the section, 6 to 1 inclusive, are largely covered up. All of the limestone ledges were used in heavy masonry work, and blocks of nearly any desired dimensions were obtainable. The base of the section is approximately twenty feet above the river. Coal blossom appears near water level in the river. The location of these quarries is favorable for supplying stone to Adams, Cass and Montgomery counties but their development has been and will be hindered by lack of transportation facilities and by the heavy stripping required.

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[*] E. H. Lonsdale, Iowa Geol. Survey, Vol. IV, pp. 393 and 435.

Limestone and shale appear at a few points farther north along the West Nodaway and its branches, but always under heavy overburden. Near the southeast corner of section 20, Edna township, stone has been removed. The limestone beds appear also at points on Seven Mile creek, notably near Galion in Bear Grove township.

On the East Nishnabotna river near Lewis, and on Turkey creek, its principal tributary from the east, the Missouri strata appear in places. Stone has been taken from the west bank of the river on the farm of George Roberts, southwest of the town. At present, there is exposed one foot of light gray limestone overlying eight to ten inches of yellow clay and soft, disintegrated limestone. The lower bed is fossiliferous, and is approximately thirteen feet above water in the river. The exposure is covered with drift and loess aggregating fifteen to twenty feet.

Two miles north of Lewis on Turkey creek, in the northwest quarter of section 1, Cass township, ten inches of blue, hard, partially crystalline limestone outcrop in a ravine a few hundred feet back from "Rockyford," where limestone was formerly quarried. In the northeast quarter of section 1, six feet of weathered limestone are in view in ravines leading into Turkey creek, in places overlain with Cretaceous sandstone and plastic clays. Throughout, all exposures in this part of the county are covered with ten to sixty feet of superficial materials, which renders utilization out of the question.

CLARKE COUNTY.

The Missouri underlies practically the whole of Clarke county, but good exposures are rare, owing to the heavy drift mantle and the nonindurated character of the stratified rocks. Limestone beds outcrop along the south branch of Whitebreast creek in Green Bay township, about six miles south of Osceola, and numerous crops appear along the south branch of Squaw creek in Ward township. Several quarries have been opened along the creek named, and a large quantity of stone has been quarried and used for foundations in the principal residences and many of the business blocks in Osceola. Two quarry sections given below afford a fair idea of the beds of commercial value.

The Carpenter quarry, located four and one-half miles northwest of Osceola, and about one-fourth mile west of Squaw creek:

		FEET.
5.	Drift, with limestone bowlders, variable in thickness; attains great thickness in the bluff, at the face....	2-4
4.	Limestone, hard, brittle; ledges uneven, gray to blue, weathers almost white; fossiliferous; 2 to 4 inch clay partings near the base.......................................	7
3.	Limestone, shaly to clayey, in places clay only..............	1
2.	Limestone, hard, tough, fossiliferous; ranges from gray to blue. The upper layers are fairly even, and range from 6 to 8 inches in thickness................................	4
1.	Shale, exposed..	4

The following section is taken from the vicinity of Short's quarry, which is located in the northwest quarter of the southeast quarter of section 2, Ward township:

		FEET.
7.	Drift and weathered limestone...........	4-10
6.	Residual clay...	1⅙
5.	Compact, gray limestone in 5 ledges: 8 inch, 14 inch, 2 inch, 2 inch clay parting, 4 inch, 1 inch clay parting, 14 inch ledge. Total...	3¾
4.	Fossiliferous, gray limestone separated from number 3 by 2 inches of clay..	1⅙
3.	Buff limestone, hard and fossiliferous below, separated by thin clay seams..	1
2.	Soft, weathered limestone............................	1
1.	Buff limestone, passing into gray, fossiliferous ledges below.	2⅚

Building stone only is produced.

One-half mile farther up this creek at the Carter quarry, the limestone is seen to rest on a heavy bed of yellow to bluish calcareous shale, nine feet thick, eight inches of which are exposed.

DALLAS COUNTY.

The Missouri occupies a triangular area in the southwestern corner of Dallas county. Exposures are limited to Adams and Union townships. The beds consist of a series of shales and limestones, all of which belong to the Bethany sub-stage. Two principal limestones can be recognized and are believed to correspond to the Fragmental and Earlham horizons. The best sections appear along Bear creek and its tributaries, and a number of the outcrops have been quarried quite extensively. The sections given below may be taken as a fair average.

An abandoned quarry in the southwest quarter of section 28, Adams township, shows:

		FEET.
9.	Drift of variable thickness.	
8.	Limestone thinly bedded, slightly arenaceous	6
7.	Talus slope	8
6.	Limestone	4
5.	Shales, gray, calcareous	⅔
4.	Limestone	¼
3.	Shales, gray	4
2.	Limestone, fragmental	2½
1.	Des Moines series, exposed about	60

In the operation of the quarry, number 4 was the lowest bed removed. The quarry is located well up toward the top of the hill, and the limestone does not appear to extend much farther to the east and north of this point. The same beds may be viewed along the east and west road about a half mile south of the above quarry, in section 32. The quarry was operated at one time, a switch being extended from the Chicago, Rock Island and Pacific railway. Large quantities of stone were shipped. Most of it was used for railway ballast and construction.

Brown quarry section located on the southeast quarter of section 22, Union township:

		FEET.
8.	Drift and weathered material	1
7.	Limestone	10
6.	Talus slope, probably shale	6
5.	Shale, black, fissile	½
4.	Limestone, blue, compact, exposed	⅔
3.	Talus slope	25
2.	Limestone, impure and fragmental below	3
1.	Shale, calcareous, ferruginous, exposed	3

The above quarry was opened about fifty years ago, and was worked continuously for more than forty years. The rock quarried is No. 7, which is a blue to buff, compact and evenly bedded limestone. The individual ledges vary in thickness from eight to ten inches, and are separated by shale partings. Chert nodules in well defined bands appear at certain horizons.

The upper limestone member, No. 7, is also well exposed in a quarry on the southwest quarter of section 35, just north of the Madison county line. It has a thickness at this place of twelve to fourteen feet, and is underlain by blue shales. The quarry was opened more than 20 years ago, and formerly was connected by a switch with the Spirit Lake branch of the Chicago, Milwaukee and St. Paul Railway. The rock utilized was the heavy bed of rough limestone. Almost the entire product of the quarry was used as crushed stone, and was shipped to Des Moines, and employed in the concrete foundations of the brick pavements. The amount of stripping was large, and added greatly to the cost of quarrying. The quarry has long since been abandoned.

Small quarries have been opened from time to time at other points in the Upper Coal Measures in the vicinity of Adel and Waukee, but these were operated intermittently, and were of local importance only.

DECATUR COUNTY.

The Missouri stage is represented in Decatur county by the Bethany sub-stage, which comprises four, possibly five, well defined limestones, interbedded with variable shales, in the main calcareous. The basal limestone member represented in the county is known as the Fragmental, and is typically exposed at Bethany, Missouri. Exposures in the county are not important, and are usually obscured by the overlying drift and by talus from the beds above. Where it is typically developed, it is not sufficiently indurated and uniform in texture to be a desirable bridge or building stone. It could be used, however, for road work, concrete, and railway ballast. So far as known, it has never been utilized in Decatur county. All of the limestones are essentially non-magnesian, are of great purity, and as a rule, contain little iron pyrite or other objectionable constituents.

The Earlham limestone appears in sections along the Grand river, in the vicinity of Davis City, and in Burrell township along Pot Hole creek. At both of these points, some quarrying has been done, the largest quarry in the county being located at Davis City, at which place the Boswell quarry shows the following section:

		FEET.
6.	Soil and loess	2-4
5.	Limestone	1
4.	Rotten stone and shale	2
3.	Limestone, 14-inch ledge overlying a 3-inch ledge	1½
2.	Shale and rotten stone	1
1.	Limestone, with wavy bedding, ledges running from 3 to 16 inches	6

The courses appear to be somewhat persistent, but are variable in thickness. A black shale appears below the basal limestone and this shale is in turn underlain by the Fragmental limestone. Higher in the bluffs, the Winterset limestone appears. On Pot Hole creek, the section given below is exposed and may be taken as fairly representative:

		FEET.
3.	Limestone, ash gray to brown, fine-grained, thin-bedded, with courses up to 1 foot in thickness, and shale partings	6-10
2.	Shale, drab, imperfectly exposed, but showing 1 foot of black shale	10
1.	Limestone, brecciated or fragmental type, firmly cemented and apparently non-fossiliferous	4

The beds dip to the west here, and higher up the stream the Winterset appears in the hills. Some quarrying has been done on the opposite side of the river, and blocks of considerable thickness still mark the site of the old quarries. It is reported that stone from this quarry was formerly dressed and sold for monumental work.

The Winterset limestone exhibits good exposures in the vicinity of Lamoni, along Hall and Elk creeks, in Bloomington township, in addition to the localities already mentioned in discussing the Earlham. One of the best sections appears along Pot Hole creek, about five miles northeast of Lamoni, and is given below:

		FEET.
6.	Limestone (Winterset) with *Spirifer cameratus*; *Productus punctatus*, *Productus costatus*, *Athyris subtilita*, etc	15
5.	Shale, gray to drab	3½
4.	Shale, bituminous	2½
3.	Coal	½
2.	Shale, gray	6
1.	Limestone (Earlham) in bed of creek.	

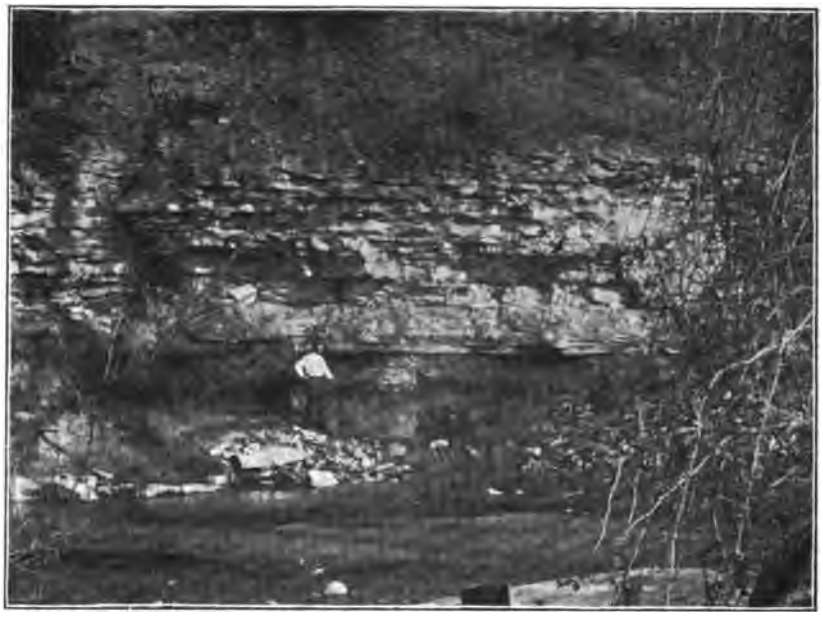

FIG 40—Winterset limestone on Pot Hole creek with shales below extending down to the Earlham limestone.

In nearly all sections of the Winterset, in addition to the shales above and below, one or more of the other limestone members of the Bethany sub-stage are present.

The DeKalb member is exposed both east and west of DeKalb station, and at numerous other points in the county. The sections given below may be considered fairly representative:

SECTION EAST OF DE KALB STATION.

		FEET.
6.	Stripping, bowlder clay	6
5.	Limestone, irregular and waterworn	½
4.	Shale, hard	½
3.	Limestone, irregularly bedded	¾
2.	Shale or bastard rock	2
1.	Limestone in five ledges that are respectively 9, 12, 6, 13, and 8 inches in thickness	4

SECTION ONE MILE WEST OF DE KALB STATION.

	FEET.
4. Limestone	1
3. Limestone	½
2. Limestone	⅓
1. Limestone	½

A fifth limestone horizon belonging to the Bethany and present in the county was recognized by Bain, who designated it provisionally as the Westerville limestone. It is typically exposed near Westerville, in Union county. It has not been quarried to any considerable extent in Decatur county. It occurs in the hills along Sand creek, attains a thickness of ten feet and is quite readily accessible. It is separated from the DeKalb by the usual shale layers. All of the limestones represented occur in comparatively thin beds ranging from three to sixteen or even eighteen inches in thickness, are fairly persistent, each horizon rarely exceeding fifteen feet in thickness, and are quite uniform in composition. They do not resist weathering influences well. After undergoing repeated freezing and thawing, they are subject to spalling, and the ledges break down rapidly on exposure. While quarrying operations have been carried on somewhat intermittently for more than half a century, very little stone is produced at the present time. There is but a single crusher in the county and that is located at Davis City. The general quarry products consist of rubble, rough stone for foundation and well purposes, and crushed stone. In the early history of the county, lime was burned at several points. On account of the high percentage of calcium carbonate and the lack of siliceous and clayey impurities, the lime was white, and in slaking, produced considerable heat, not necessarily objectionable features for some purposes, but producing a weaker mortar than can be secured from the magnesian limestones.

Owing to the establishment of large plants at Ash Grove, Springfield, and other points in Missouri, the cost of producing lime was greatly cheapened. The local plants were unable to compete, and were discontinued.

FREMONT COUNTY.

The Missouri as exposed in Fremont county comprises a complicated series of interbedded limestone bands and shales. While numerous limestone beds are present, and are fairly persistent, none are of sufficient thickness to merit distinctive names or individual notice. In general the individual beds rarely exceed four feet in thickness, and are almost inaccessible on account of the excessive overburden. Some quarrying has been done, mainly along the base of the Missouri river bluff. A few unimportant openings have been made in the interior of the county in the vicinity of Riverton, and along Plum creek, in Green township. The only quarries which have been in operation recently are in the vicinity of Thurman in Scott township. The limestone beds when first exposed appear to be well indurated, and the layers range from four to eight or ten inches in thickness, occasionally attaining even greater thicknesses. The stone is used for rough masonry, such as foundations for buildings, well-curbs, retaining walls, and other rough work. On exposure to the elements, it does not resist weathering well, but rapidly takes on a pseudo-concretionary structure, evidently due to its fragmental character and imperfect cementation. This effect is well shown in the retaining wall north of Thurman along the Thurman-Bartlett wagon road. All of the limestones appear to be

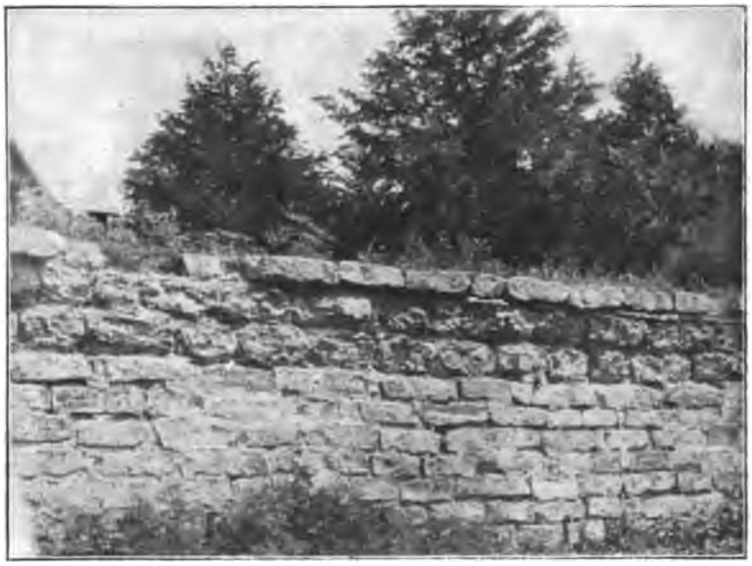

FIG. 41—Retaining wall north of Thurman showing characteristic weathering of Missouri limestone as developed in the immediate vicinity.

non-magnesian; on account of their limited thicknesses and heavy overburden, they are never more than of local importance. The following sections may be considered fairly representative.

Section in the bluff near the south line of section 14, Scott township:

		FEET.
9.	Thick loess cover.	
8.	Limestone, fine-grained, oölitic texture	3
7.	Limestone, impure, fossiliferous	2½
6.	Limestone, gray, massive, with thin shaly partings	11
5.	Limestone, gray, highly fossiliferous	½
4.	Shale, gray, with black shale partings	1½
3.	Limestone, bluish, with occasional crinoid stems	1
2.	Shale	1½
1.	Coal reported	1½

Section on Mill creek, near the center of the southwest quarter of section 33, Riverton township:

		FEET.
10.	Drift and loess of indefinite thickness.	
9.	Shale, weathered, yellow	10
8.	Limestone, gray to white, with greenish shale partings, somewhat pyritic, small blocks of durable stone obtainable	3
7.	Limestone, weathered, marly, iron-stained	2½
6.	Shale, blue to black, calcareous, with yellow blotches and small compact concretions, slightly arenaceous	4
5.	Talus slope, probably limestone	2
4.	Sandstone, fine-grained, soft	⅛
3.	Silt, shaly, and friable	4½
2.	Sandstone, fine-grained, calcareous, varying in color from bluish gray to brown, well indurated	2
1.	Shale, bluish gray, with reddish arenaceous seams, and large irregular calcareous concretions lodged in the vertical or inclined joints	8

Numbers 1 to 4 inclusive, appear in the bed of Mill creek but are not well exposed.

GUTHRIE COUNTY.

Suitable material for building purposes is to be had from the Missouri, in Guthrie county. Strata belonging to this stage are known to be present over about one-third of Beaver township and to occupy essentially the whole of Penn in the southeast corner of the county. This stage is represented by the Fragmental and Earlham limestones of the Bethany and by a portion of the Winterset section. Those rocks appear along the lower portion of Beaver creek, Deer creek, Long Branch and South Raccoon river, in ledges varying from six to twenty-four inches in thickness and separated by shaly or clayey partings. The following typical section taken from the *Geology of Madison County,*[*] will serve to show the nature and succession of the beds. It is taken from along Deer creek, section 19, Penn township. Good exposures are lacking as the stone has not been quarried extensively at any point.

		FEET.
5.	Limestone, coarse, gray; with Fusulina similar to that occurring at Winterset	2
4.	Shales, exposed only in part	8
3.	Earlham limestone, ash gray, with conchoidal fracture, in layers two to ten inches thick, separated by shale partings	12
2.	Shale, gray, argillaceous, becoming bituminous and slaty at the top	10
1.	Limestone, fragmental, made up of irregular bits of lime rock filled in with calcareous clay. In places the rock can be picked to pieces with the fingers; elsewhere it hardens up into massive layers two feet in thickness	10

The lowest member of this section rests on sandy shales which form the top of the Des Moines stage. Ten to thirty feet of loess and drift overlie the exposures along Deer creek, and wherever the beds appear along the other streams mentioned they are also invariably buried beneath a heavy mantle of the same material.

HARRISON COUNTY.

Exposures of formations older than the Pleistocene are found in Harrison county at a few points along the Boyer river. At Logan, both above and below the mill, limestone has been quarried at the east side of the river valley. Some six miles farther up the river, and two miles below the town of Woodbine, considerable stone is said to have been quarried in the left bank of the Boyer.[†] The strata are prevailingly limestone, and belong to the Missouri stage of the Upper Carboniferous. So far as known, they are the most northern exposures of these measures in Iowa.

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[*] J. L. Tilton and H. F. Bain, Iowa Geological Survey, Vol. VII, p. 448.

[†] C. A. White, Geology of Iowa, Vol. II, 1870, p. 180.

No stone is now taken out at either of these localities, and the old quarry faces are greatly obscured by rock debris. The following section is in view just above the mill and across the river from the town of Logan:

		FEET.
5.	Loess, passing into sands below	40+
4.	Sand, containing coarse gravel and bowlders of a variety of igneous types, plainly Pleistocene	1½
3.	Limestone, decayed above, and splitting irregularly along bedding planes; color buff, contains much crystalline calcite, and is fossiliferous. *Productus longispinus*, *P. costatus* and *Spirifer cameratus* are abundant. Ledges are but a few inches thick, and but small blocks can be obtained	1
2.	Limestone, coarse in texture, composed largely of a shell breccia. *Spirifer cameratus*, *Athyris subtilita* and crinoids are common. Badly weathered and iron-stained in places, the iron frequently distributed in concentric bands, giving the appearance of a sandstone; occasional nodules of both light and dark chert	½-⅔
1.	Limestone, gray to blue, splitting in ledges a few inches thick; highly fossiliferous; said to extend down several feet. Breaks into small blocks, but is the principal quarry stone, exposed	2

A face perhaps 100 feet in length is open at this point. The base of this section is about three or four feet above the water in the river, which is but fifty feet distant. While the rock is suitable for ordinary rough work, quarrying has been limited by the excessive overburden. This same factor determines the amount of stone available in the other localities mentioned. Since the county is in general covered with a great thickness of recent deposits, which require removal, the production of stone will of necessity be very limited in the future.

MADISON COUNTY.

The Missouri limestones underlie about two-thirds of Madison county, and belong entirely to the Bethany sub-stage. The four limestone members representing this sub-stage are well represented in the county and all may be observed along Middle river in Lincoln township. A composite section, produced by blending the beds exposed along the ravine in section 22 in Lincoln township with the lower beds which may be seen in the locality of the Devil's Backbone, is as follows:

		FEET.
13.	Glacial debris variable in character and thickness.	
12.	Limestone, yellow, earthy; thinly bedded, Fusulina zone	4
11.	Shale, variable in color and composition, bisected by compact limestone and decidedly calcareous above	13
10.	Limestone, coarse, with shaly partings	3
9.	Shale, dark, carbonaceous in part and with calcareous, fossiliferous bands	8
8.	Limestone, blue, fossiliferous, with shaly partings	3
7.	Shale, dark above; lighter and calcareous to marly below	5
6.	Limestone, yellowish above, shaly partings below	17
5.	Shale, black above; variable, earthy, yellowish, calcareous beds below	7
4.	Limestone, with shale partings	12
3.	Shale, black above, arenaceous below; the two members separated by a thin band of limestone	18
2.	Limestone, exhibits a nodular structure in weathering; fragmental, with shale parting near the middle	9
1.	Shale, exposed	20

Number 2 in the above section corresponds to the Fragmental phase of the Bethany, typically developed at Bethany, Missouri, and forms the ledge over which the water falls at the Backbone mill. Number 4 represents the Earlham, number 6 the Winterset, and number 12 the Fusulina or DeKalb phase, according to Bain in his Decatur county report. All of the members are comparatively pure, the limestone being essentially non-magnesian and reasonably free from iron pyrite. The associated shales are usually more or less calcareous and often carry considerable of the iron sulphides. The two middle limestone members are the ones most widely distributed in the county, and are the only ones quarried extensively.

The Fragmental limestone apparently occurs in heavy beds in fresh exposures, but where the beds have been exposed some time, they readily show their fragmental character, and are practically worthless for structural purposes.

The Missouri limestones are responsible for a prominent topographic feature producing a well marked escarpment which crosses the county diagonally in a northwest-southeast direction. The principal streams cross the escarpment at right angles and the most important outcrops occur where the streams debouch on the Lower Coal Measures. Quarry opening has been limited to the streamways which have railway facilities, and three centers are worthy of mention. These, named in their order from northwest to southeast, are as follows: Earlham, Winterset, and Peru. Unimportant quarries have been opened and operated from time to time at numerous other points but at present do not merit individual mention.

The Earlham beds have been most extensively quarried and afford a fair grade of stone suitable for dimension stone, rubble, and crushed stone. Near Earlham two quarry companies have operated extensively, and are directly connected with the main line of the Rock Island Railway. The first is owned and operated by the Earlham Land Company with offices in Des Moines, and is located about one and one-half miles south of the railway station in Earlham, along the north branch of North river. The section exposed is as follows:

EARLHAM LAND COMPANY. QUARRY SECTION.

		FEET.
4.	Loess and drift, of variable thickness	10-14
3.	Limestone, in regular beds, with shale parting near the middle	9
2.	Limestone, less evenly bedded than the above, hard and brittle	6
1.	Sandstone, calcareous and shaly, exposed.	

The second is located along the main line of the Chicago, Rock Island and Pacific Railway two miles east of the town of Earlham, on Bear creek, and is owned and operated by S. A. Robertson of Des Moines. The sequence of beds is as follows:

ROBERTSON QUARRY.*

		FEET.
7.	Loess and drift, variable	2-8
6.	Limestone, gray to buff, evenly bedded	2
5.	Limestone, irregularly bedded, with some cherts	3
4.	Limestone, evenly bedded, becoming shaly near the middle	4
3.	Limestone, shattered, unevenly bedded, cherty	1½
2.	Limestone, rather evenly bedded above, and unevenly bedded below. Hard and compact, but in thin ledges	6
1.	Sandstone, calcareous and shaly, exposed.	

*At the present time owned by the Iowa Portland Cement Company and will supply the raw materials for their Des Moines plant.

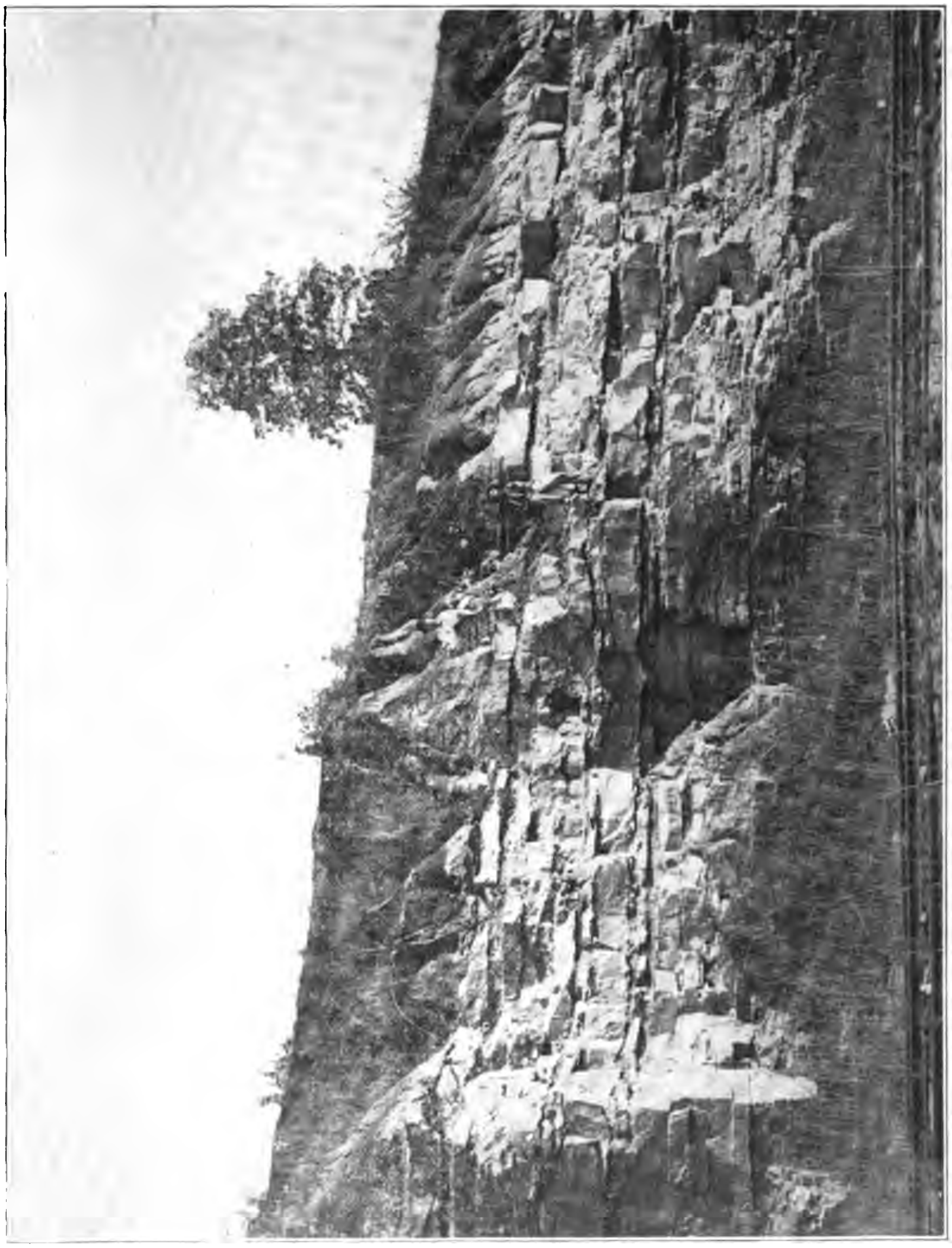

PLATE LIX—S. A. Robertson quarry, Earlham, Madison county, Iowa, showing the principal limestone beds with their characteristic clay partings.

A composite sample was selected from the Robertson quarry and analyzed. The result of the analysis is given below:

Insoluble	7.85
Iron oxide and alumina	1.00
Calcium carbonate	91.15
Magnesium carbonate	0.61

L. G. MICHAEL, Analyst.

The beds lie almost in horizontal position, and have little overburden. Most of the quarrying here is done by hand methods, although the plant is equipped with steam power, tram cars, and rope haulage. The product consists of dimension stone, rubble, and crushed stone. Practically all of the waste resulting from the quarry operations is sent to the crusher, the plant being equipped with a Gates Gyratory crusher, an elevator, and revolving screen. While the plant has a capacity of 200 yards of crushed stone per day, it is operated only intermittently.

The quarry of the Earlham Land Company has also been worked only intermittently during the past few years. The amount of overburden is rather greater than at the Robertson quarry. The equipment and quarry methods employed and products put upon the market are practically the same at both quarries.

The Winterset limestone has been most extensively developed in the vicinity of Winterset. The stone used in the Madison county court house was obtained from the local quarries. The building was erected about thirty years ago, bearing the date of 1876, and all parts are in an excellent state of preservation save some of the stone steps, and one or two of the large columns, which show signs of failure due to selection of poor materials. One of the porch columns has become roughened owing to the presence of "clay balls" which appear to be one of the most serious defects in the stone but could be avoided by careful selection. Several of the steps have been replaced while others show signs of weakness. The failure in this instance was due to spalling and opening of cracks along bedding planes. The most of the materials used in the court house were obtained from the quarry in the northwest quarter of section 12 and the "Backbone" quarry, both in Lincoln township.

A good section showing the Winterset beds may be viewed within the city limits about a half mile southeast of court house square. The sequence is as follows:

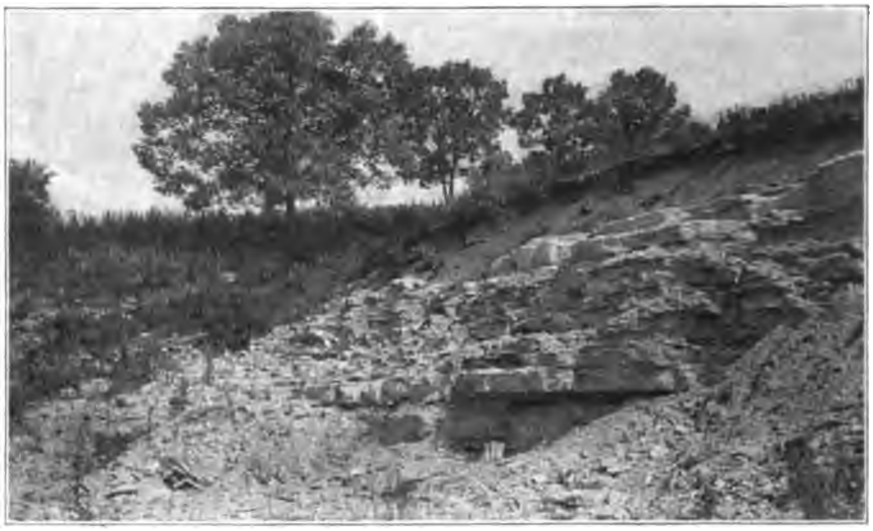

FIG. 42—Winterset quarry located about one-half mile southeast of the court house, Winterset, Madison county, Iowa.

		FEET.
7.	Drift and soil (thickens greatly in the bluffs)	3
6.	Limestone, disintegrated, uneven on the upper surface and probably thickens toward the bluffs, exposed	3
5.	Limestone, gray, heavy-bedded, somewhat porous and fossiliferous	3
4.	Limestone, fossiliferous and presents a concretionary facies; decidedly argillaceous	1½
3.	Limestone, gray to buff, hard, brittle and fossiliferous; unevenly bedded, top and bottom layers thickest, slightly concretionary	8
2.	Limestone, shaly, gray to yellow, highly fossiliferous	1½
1.	Limestone, buff to gray, somewhat unevenly bedded and slightly clayey; massive in unweathered sections, exposed	4

The base of the above section is about sixteen feet above the roadway, which follows the ravine down to Middle river. A black shale band appears in the bluff about ten feet above number 6 in the section.

Although important shales are not exposed in the immediate vicinity, an abundance of shale occurs within easy reach, but is usually more or less obscured by the heavy talus from the superincumbent deposits. East of Winterset, in the pit of the Winterset Brick and Tile Plant and in the cut along the wagon roadway leading north from the plant, the following beds may be viewed:

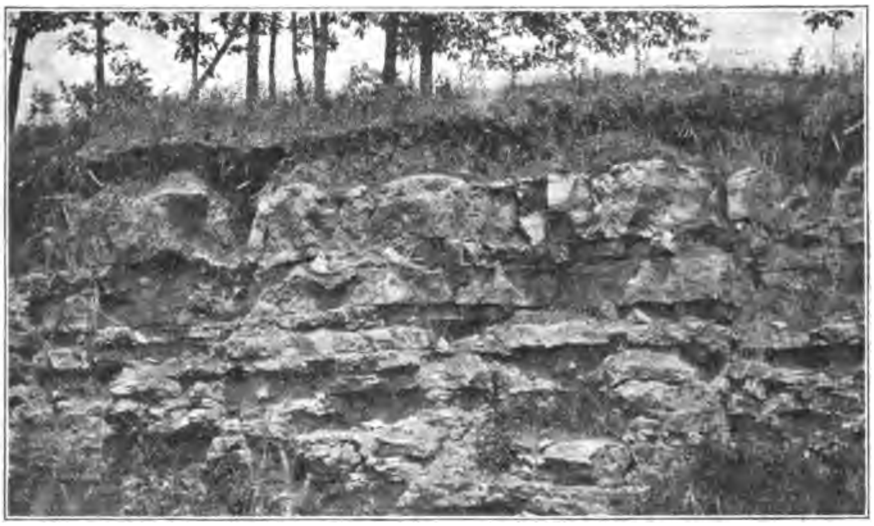

FIG. 43—Quarry near top of hill southwest of Winterset, showing limestone above the black shale which appears well up in the ravines south of town.

Roadway and pit section of the Winterset Brick and Tile Company:

		FEET.
7.	Drift and soil, oxidized a deep red below the soil zone; lower portion contains lime concretions	0-10
6.	Limestone, blue-gray to iron-stained yellow; beds exposed along roadway; do not run more than six inches in thickness. Occasional shale partings ranging from a few inches to more than a foot in thickness appear throughout the section	25
5.	Shale, black, carbonaceous	2
4.	Talus slope (probably shale, in part at least)	20-30
3.	Shale, plastic, gray-blue	10-15
2.	Shale, arenaceous	10
1.	Shale, plastic, variegated, blue-gray to red	8

The lower shale members, numbers 1 and 2, have been sampled and analyzed. An average sample was selected from the Winterset quarries and analyzed. The results of both sets of analyses are given herewith:

	1.	2.
Silica (SiO_2)	64.74	26.72
Alumina (Al_2O_3)	18.07	3.83
Ferric iron (Fe_2O_3)	6.90	3.11
Lime (CaO)	1.25	36.08
Magnesia (MgO)	1.30	0.48
Potash (K_2O)	1.09	1.12
Soda (Na_2O)	0.41	0.18
Sulphur trioxide (SO_3)	0.15	0.22
Moisture	1.99	0.55
Loss on ignition	4.15	28.40
Totals	100.05	100.69

A. O. ANDERSON, Analyst.

Number 1 represents an average sample taken from the pit of the Winterset Brick and Tile Company.

Number 2 represents the clayey partings in the Winterset limestone.

Analysis of Winterset limestone selected from City quarry.

Insoluble	12.63
Iron and alumina	1.18
Calcium carbonate	84.34
Magnesium carbonate	2.19
Moisture	0.02
Total	100.36

Similar limestone deposits are to be found along the Chicago Great Western railway at Peru. According to T. E. Savage, the beds exposed at this point are as follows:

		FEET.
10.	Yellow colored loess	5-8
9.	Drift, reddish brown above grading down to gray below; containing numerous bowlders in the lower portion	9 15
8.	Gray or yellowish limestone, argillaceous, fine-grained; in three layers respectively 15, 18, and 12 inches in thickness. Much stained in upper part	4¾
7.	Bluish colored shale, with a band of limestone 1 to 5 inches in thickness near the middle portion	1⅝
6.	Dense, gray limestone, in layers 16, 24, 6 and 16 inches in thickness	5
5.	Band of gray shale	⅛
4.	Layer of gray limestone, crinoidal in lower portion	2¼

		FEET.
3.	Ledge of gray limestone similar to number 4 above, in two layers respectively 12 and 30 inches in thickness	3½
2.	Band of grayish blue shale	1⅝
1.	Talus slope with occasional outcrops of limestone, to level of flood plain	20

The principal product of the quarry at the present time is crushed stone, which is used extensively in and about Des Moines.

According to Mr. Savage the bluff continues a distance of one-half mile along Clanton creek. A composite sample was selected from the limestone members of the above section and analyzed, and the results of the analysis are given below:

Silica	17.16
Iron oxide and alumina	2.64
Calcium carbonate	72.76
Magnesium carbonate	2.86
Sulphur trioxide	0.95
Moisture	0.30
Combined water	3.12

Analyzed by L. G. MICHAEL.

Lime of acceptable quality was formerly burned at several points in the county, viz., Winterset, Peru, and in Jefferson and Madison townships. The industry never attained any considerable importance, and was abandoned on the introduction from other districts of limes which were of better quality and could be produced more cheaply.

MILLS COUNTY.

The constitution of the Missouri in Mills county is almost an exact duplicate of the stage in Fremont county to the south. The shale members greatly predominate, and as before, the exposures of the indurated beds are limited almost wholly to the bluffs facing the Missouri river. A few exposures are found elsewhere, especially along the Nishnabotna river and its immediate tributaries. While the limestone ledges appear at a considerable number of points, quarrying operations have been carried on at a very few, and the probabilities are that the industry will never attain any importance in the county. The leading sections are given below.

Section in the bluffs in the southeast quarter of section 16, Lyons township:

		FEET.
13.	Loess and drift of indefinite thickness, which reach great depth immediately back from quarry face, average	18
12.	Limestone, oölitic above and compact below	3
11.	Shale, gray, with two calcareous stone layers about 3½ and 4½ feet from the upper surface, fossiliferous throughout	6½
10.	Limestone	1
9.	Shale, gray, calcareous and fossiliferous	1
8.	Limestone with a band of chert	1¾
7.	Shale, gray and black, slightly calcareous, with occasional streaks or pockets of coal	1½
6.	Limestone, compact, white, breaking preferably along vertical planes	1
5.	Shale, varying from slightly to highly calcareous	2
4.	Limestone, gray, fragmental, some of the fragments clean and some covered with oölitic crust, all imbedded in a fine-grained matrix	3½
3.	Limestone, shaly, grading into 4	1
2.	Limestone, yellowish gray, in heavy ledges, showing a tendency to wedge out, shale partings present	4
1.	Shale, bluish gray to black, and talus	8

The above is the most important section in the county, and continues along the bluff for about half a mile. Extensive quarrying was carried on formerly, but the industry has been practically abandoned. Number 2 appears to have furnished the most important quarry stone. A small quantity of stone is now burned for lime at this place.

Section formerly exposed in the quarry near the Missouri river bluffs, at Mills station:

		FEET.
6.	Loess and drift of variable thickness	50-60
5.	Disintegrated limestone containing ***Fusulina cylindrica***	½
4.	Yellow shale or disintegrated limestone containing ***Fusulina cylindrica***	2½
3.	Limestone, decayed and yellow above, gray and sound below, containing numerous nodules of fossiliferous chert	3
2.	Concealed, probably shale	2
1.	Bluish, dark gray limestone	1

Only No. 3 is now visible in above section. The same stone appears in the stream channel south of the railroad.

Section in the quarry at Henton:

		FEET.
5.	Loess and drift of variable thickness.	
4.	Shale, gray, with thin calcareous layers and occasional small calcareous concretions	2
3.	Limestone, gray or yellow	1½
2.	Limestone, gray to cream colored, with dark cherty concretions several inches in diameter, somewhat pyritic	I
1.	Limestone, light bluish gray, in heavy ledges with some shale partings, and irregular nodules of chert; fossiliferous	3

Several small quarries have been opened in this vicinity. Quarrying operations have, however, been carried on only intermittently, and then in a dilatory way. Away from the Missouri bluffs, very few quarries have been opened, although the limestone members are occasionally exposed. The section given below shows more limestone than the average.

Section near the banks of Silver creek, one-third of a mile west of the center of section 5, White Cloud township:

		FEET.
7.	Loess and gravelly drift	17+
6.	Shale, marly	½
5.	Limestone, grayish yellow, in three or four heavy ledges, cherty and cavernous	6
4.	Limestone, grayish blue, compact	¾
3.	Talus slope	2
2.	Limestone, yellow, fragmental	2
1.	Limestone, formerly quarried, but now concealed to water level of Silver creek, about	3

These beds are much obscured, the outcropping edges of No. 5 being the only stone visible in place. Quarries were formerly operated in section 36, Rawls township, the upper ledge being striated. Stone is no longer quarried in the vicinity.

MONTGOMERY COUNTY.

Strata belonging to the Missouri stage of the Upper Carboniferous underlie the whole of Montgomery county. They are covered in part by Cretaceous beds, but are exposed at a large number of places along the principal streams. Carboniferous strata are the country rock of all lowlands, where the drift or alluvial beds rest directly upon them.

The principal exposures of economic importance occur along East Nishnabotna river and Walnut creek in the western half of the county, and on the lower course of Tarkio river and the upper course of the West Nodaway in the eastern part of the county. The quarry industry is not at present in a very flourishing condition, but stone suitable for common building purposes has been taken out at times from a score or more of different places. Many of the quarries that were formerly worked on a scale of some magnitude are now abandoned and good, unobscured sections are somewhat difficult to find.

The town of Stennett in the southern part of Sherman township is the center of what has been the most extensive quarry operations in the county. Lonsdale* records in his report on Montgomery county in 1895, nine working quarries in this district. Some dressed stone was produced and large quantities were shipped. At present stone is being taken from but one opening, the W. Stennett quarry, and this is sold locally. The section here as given by Lonsdale is as follows:

		FEET.
12.	Soil and loess	8
11.	Clay, residuary, red to brown in color	1⅛
10.	Limestone, weathered	2
9.	Shale, argillaceous	½
8.	Limestone, hard	1⅜
7.	Shale, clayey, buff to gray	3½
6.	Limestone, earthy, in part ocherous	2½
5.	Limestone, shaly	3
4.	Limestone, impure, earthy	1
3.	Limestone, hard, sub-crystalline	⅜
2.	Limestone, contains much dark chert	½
1.	Limestone, in thin layers	6

Number 8 is persistent in all exposures in the vicinity, and is one of the principal ledges used. It is hard, blue in color, and a very good building stone. As observed in the quarry, the other beds appear less stable under weathering influences. Occasional thin bands of shale separate the limestone ledges in most exposures. An overburden of two to eight feet of soil and loess is usually present, and this, along with on an average of five feet of worthless stone, must be stripped.

The principal quarries that have been worked here are located in sections 22, 26 and 27, of Sherman township. There are considerable areas in this vicinity in which the limestone is not

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*Iowa Geological Survey, Vol. IV, 1894.

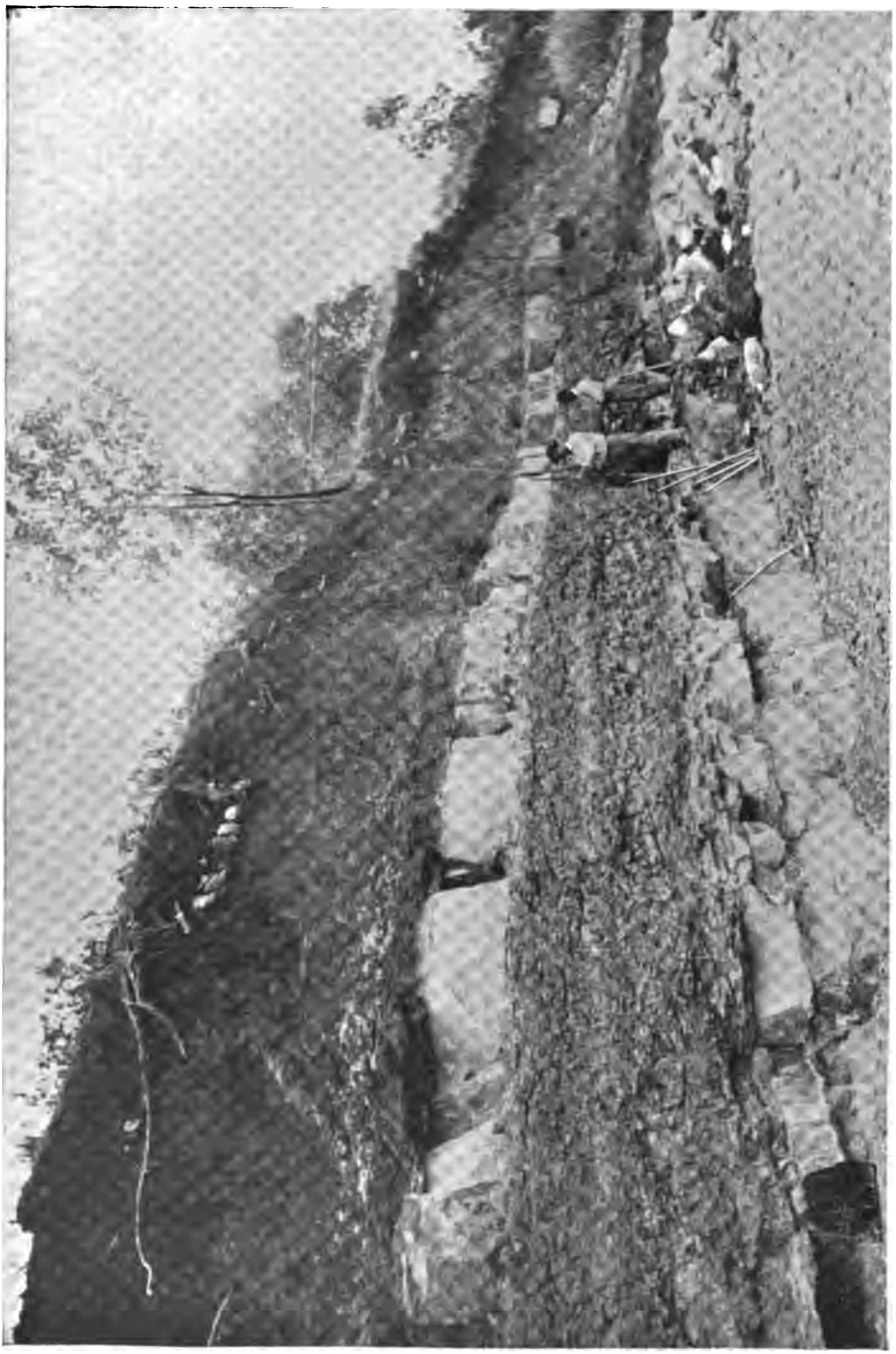

PLATE LX—Typical exposure of the Missouri stage of the Coal Measures. Fate quarry, Stennett.

far beneath the surface, and where it would be available without an excessive amount of stripping. Near the southeast corner of section 21, and in section 22, along a small tributary, is exposed a thickness of some twenty-six feet of limestone strata, the principal layers of which are lower than the Stennett quarry section given. A maximum depth of twenty feet of loess covering is present a little back from the present face.

Following is the section at the old McCalla quarry, in the southwest quarter of the southeast quarter of section 23, Sherman township:

		FEET.
13.	Soil	1
12.	Limestone, decomposed, Fusulina-bearing	1¼
11.	Clay, for the most part residual	1½
10.	Limestone, hard, light to dark gray	⅔
9.	Limestone, with black flint, hard in central part; many Fusulina present throughout	6
8.	Limestone, buff to brown in color, Fusulina irregularly distributed	1
7.	Limestone, light, 12-inch ledges; weathered	1⅔
6.	Unexposed, probably similar to No. 9	4
5.	Limestone, thin layers, shaly partings	5
4.	Limestone, hard, grayish brown; concretions of dark flint disseminated in central portions	1½
3.	Limestone, earthy	⅔
2.	Shaly partings	⅙
1.	Limestone, buff, earthy	1

Several ledges of usable stone are here available, and the covering is not thick.

Limestone has been quarried along Walnut creek, in the east half of section 1, Walnut township. The following section was formerly exposed:

		FEET.
6.	Soil and residual material	5
5.	Shale, buff to gray	⅔
4.	Limestone (decomposed), and shales	5
3.	Limestone, flint-bearing	1⅙
2.	Limestone, hard, grayish, in two ledges; very fossiliferous, dimension stone	1½
1.	Limestone, "blue layer," dimension stone	1¼

Near Climax in the southeast quarter of section 19, West township, some ten feet of the Missouri strata under a heavy overburden were formerly quarried. They were:

		FEET.
7.	Soil, loess and drift	18
6.	Limestone, hard, drab, finely textured, not fully exposed	1
5.	Limestone and shale, marly	3
4.	Shale, argillaceous, gray	2
3.	Limestone, bluish, dull, earthy	1
2.	Shale, argillaceous, gray	1
1.	Limestone, light blue, hard; dimension stone	1½

Two or three small quarries have been worked along the Middle Tarkio river and its tributaries in section 20 of Scott township, and stone has been taken out at other points northward to Stanton. The stone used came from two ledges, each about one foot thick, and separated by six inches of marly shale. The upper layer is a yellowish gray, earthy limestone; the lower, a hard, grayish blue limestone, containing particles of iron pyrite which are often oxidized to the brown hydroxide or iron rust. Both strata are suited for undressed dimension stone and for foundation work.

A small amount of stone has been removed from an opening one and one-half miles east of Villisca. But one bed of value occurs here, and it is covered with several feet of shales. From this point northward, the Upper Coal Measures can be traced along the West Nodaway to the north county line.

Suitable stone for quarrying is found in the vicinity of Grant (Milford) in Douglas township. Here a number of quarries have been worked, but from only one is stone now being removed. The section is almost entirely limestone, and the ledges vary from a few inches to more than three feet in thickness. The old Fisher quarry, located near the south edge of section 3, and west of the river, is now worked intermittently by Mr. Richard Berry. The strata now exposed are:

		FEET.
6.	Soil, loess, oxidized drift, sand and gravel	5
5.	Shale, plastic, gray to yellow	1½
4.	Shaly limestone, fossiliferous, thinly laminated and of no value	1
3.	Shale, soft, yellow	1-2
2.	Weathered limestone, nodular, yellow, marly texture; flint in lower portion, distinctly separated from No. 1	1½
1.	Limestone, filled with Fusulina which stand out on weathered faces. Many small and large flint nodules often including the Fusulina; yellow to gray in color, numerous cavities lined with calcite. One solid ledge and apparently of a fair grade	3½

The rock is exposed at the mill dam at Grant, and at other points up the river into Cass county. It has been quarried directly across the Nodaway from the Berry opening. No stone has been taken out for some time, but there is an old face some 600 feet in length along the hill-side. The covering is not excessive.

PAGE COUNTY.

The strata belonging to the Missouri stage in Page county are composed very largely of argillaceous beds, varying from typical shale to marly clays, and clayey limestones. Relatively thin beds of limestone are found in most exposures, alternating with much thicker beds of shale to such an extent as to make economical quarrying of the limestone impossible.

Two distinct horizons of Missouri limestone strata are exposed in the county, one along the East and West Nodaways, and the other principally along the Middle Tarkio river. Stratigraphically the latter come above the beds exposed on the Nodaway rivers, and are considered by Calvin to be the equivalents of the limestones quarried at Stennett in Montgomery and near Macedonia in Pottawattamie counties.

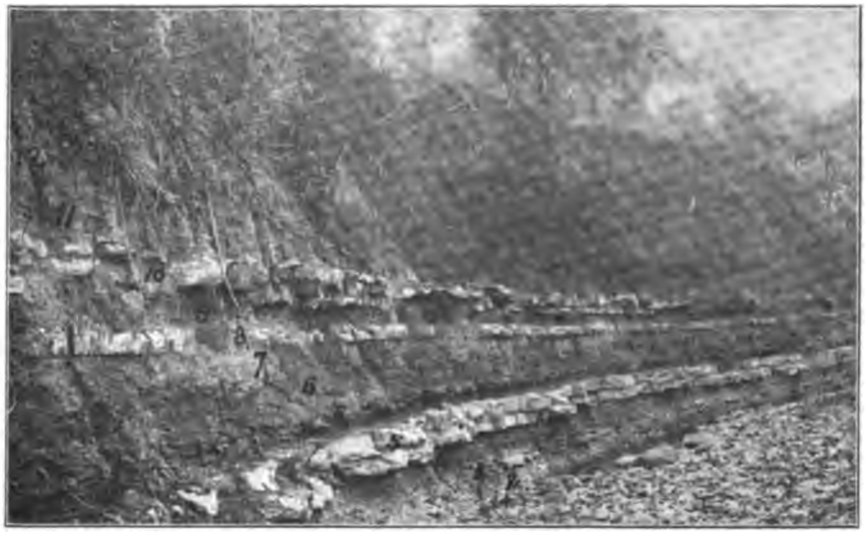

FIG. 44—Exposure of the Forbes limestone near Hawleyville, Page county

Limestone has been quarried at Coin in the southern part of Lincoln township, and the same strata have been worked at intervals along the Middle Tarkio to the north line of the county. In most places the outcropping ledges are displaced and weathered, and a section of any considerable thickness is seldom seen.

A new quarry opening on the farm of Mr. Burns near the southeast corner of the southwest quarter of section 22, Tarkio township, affords the following section:

		FEET.
5.	Drift	10
4.	Fusulina limestone	1
3.	Yellow shale	4
2.	Limestone, soft, yellow	½
1.	Blue, fine-grained, hard limestone, breaking at right angles to bedding planes into excellent blocks for building purposes. Fossiliferous, and contains occasional sphalerite grains	1½

Professor Calvin* gives a composite section from a number of openings in this same region and in section 27, which includes the following members, coming below those just given:

		FEET.
4.	Shale	12
3.	Limestone, soft, but of fair quality	1½
2.	Shale	3½
1.	Limestone	2

No. 1 is an excellent stone for a variety of purposes and is the ledge chiefly sought in all of the quarries. It is durable and the most important building stone in the county.

The next good exposure is to be seen in section 18, Douglas township, on a small tributary to the Tarkio:

		FEET.
5.	Drift, maximum of	20
4.	Fusulina limestone cap above quarry ledge	½
3.	"Blue ledge" limestone No. 1 of Burns' quarry section	1+
2.	Calcareous and fossiliferous bluish shale	7
1.	Yellow, marly clay, apparently weathered limestone	1½

As stated, the "blue ledge" is the one sought at all of the numerous small quarries along the Tarkio, the associated strata being almost universally of too incoherent a nature to be of value for building purposes. This ledge lies about eight feet above the water in the Douglas township exposures while in

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*Geology of Page county, Iowa Geol. Survey, Vol. XI, p. 430.

Tarkio and Lincoln townships it appears twenty to thirty feet above the stream. Although it crops out in both sides of the valley at intervals for miles, the heavy drift covering and its association with worthless argillaceous beds that require removal, render very limited in extent the quarrying possible at any one plant. From the natural outcop it is seldom possible, with the present hand methods of quarrying, to work back over twenty feet before the overburden becomes too heavy. Locally, however, this stone has been and will continue to be a very valuable resource to the county.

On a small branch of the East Nodaway, three-quarters of a mile above Hawleyville in Nebraska township, there is an exposure of some magnitude, composed of strata which lie, geologically, below the Tarkio beds. The section comprises alternating bands of calcareous and argillaceous material. The individual members are seldom more than a foot in thickness, and it is not probable that any of them will ever possess more than a very limited local value for building purposes. Similar beds are exposed below the mill at Braddyville in section 31, Buchanan township. At both localities the Missouri beds are overlain by heavy deposits of loess and drift.

POTTAWATTAMIE COUNTY.

With the exception of small areas near the eastern edge of the county, the underlying indurated rocks belong to the Missouri stage of the Upper Carboniferous. These are limestones and shales. In general they lie deeply buried beneath the glacial deposits and where exposed along some of the larger streams, are usually overlain with great depths of drift and loess.

There are but two districts where Missouri strata are exposed. In Carson and Macedonia townships, in the vicinity of the towns of Carson and Macedonia, several small quarries have been operated. No stone is, however, being taken out at the present time, and all exposures are greatly obscured.

At the John Marten quarry near the northwest corner of section 23, Macedonia township, the main quarry beds are covered with fifteen feet of marly shales and weathered fossiliferous limestone, above which are eight to ten feet of drift and loess. The layers quarried consist of three ledges of gray, compact limestone, each about a foot thick and separated by seams of marly material. The upper layer contains nodules of dark chert. Below the gray stone are three feet of a soft, yellow limestone filled with *Fusulina cylindrica.* Similar strata were formerly worked near the northeast corner of section 27 in the Tompkins quarry. West of the river and opposite the town of Carson in section 3 of Carson township, rock has been quarried at several points along the edge of the valley. The following section was formerly exposed on the land of Mr. David Snapp:

		FEET.
7.	Drift and loess	20
6.	Limestone, gray, hard, strong, highly fossiliferous	6
5.	Shale, gray, indurated	.7
4.	Limestone, dark, soft, of fine and uniform texture, gray to black, fossiliferous	1
3.	Shale	.5
2.	Limestone, dark, impure, fine-grained, soft	.5
1.	Shale, greenish gray, exposed	2

All of the rock ledges open to view in this district are much weathered, and of a poor grade for building purposes. These conditions, along with the heavy stripping that would be required, the thinness of the individual usable ledges, and their being interbedded with such large proportions of worthless materials, are all unfavorable to the development of the quarry business.

The Missouri limestones have been quarried at two other points in the county in past years; below the town of Crescent in sections 27 and 34, and on Mosquito creek, section 21, Garner township. At the former locality, the following strata outcrop almost continuously for three-fourths of a mile at the base of the Missouri river bluff.

		FEET.
6.	Loess and drift up to	100
5.	Limestone, yellowish to gray, in ledges six inches to one foot in thickness, occasionally brecciated and at times having a finely oölitic texture	5
4.	Shale, yellow	2
3.	Limestone, yellowish gray, compact, occasionally oölitic, fossiliferous	2

		FEET.
2.	Shale, gypseous, highly fossiliferous	5
1.	Limestone, massive ledge, fine-grained, oölitic, fossiliferous, exposed	3

These strata afford a good quality of building material, and lime was burned here many years ago. But the enormous quantity of stripping necessary to render any considerable amount of the stone available, is a barrier to further development at this point.

The Mosquito creek quarry has long since been abandoned and the strata are very meagerly exposed. Here also the extremely heavy overburden renders the further working of the quarry practically impossible.

TAYLOR COUNTY.

There seems little possibility that the quarry interests of Taylor county will attain any important development. The county is universally covered with glacial materials, and the underlying strata, where they do appear, consist largely of shales and shaly limestones. Stone has been quarried at but one known point in the county, viz., at Bedford. It is fifteen years since this quarry was worked and the ledge is almost entirely hidden from view. The stone was taken from about water level in East Hundred and Two creek at a point 100 yards north from the railroad station. The main ledge is about ten inches thick and contains abundant Fusulinæ. It splits very easily and is said to go to pieces in the weather. These qualities, along with the thick overburden, which runs twenty to thirty feet, have prevented its use.

Thin beds of limestone have been exposed in the banks of the Nodaway in the northwest corner of Dallas township, where they occur interstratified with much greater thicknesses of argillaceous strata. A detailed section may be found in *Geology of Page County*.* The factors just enumerated would prevent the utilization of these beds for structural purposes. The drift covering is more than ten feet in thickness, and the calcareous strata are of poor quality.

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* Samuel Calvin, Iowa Geol. Survey, Vol. XI, p. 423.

The Permian.

In the vicinity of Fort Dodge in Webster county a series of red clays associated with gypsum occur over a small area and comprise a well marked formation. In the earlier volumes of the present Survey these beds were referred by Keyes to the Cretaceous. The concensus of opinion at the present time favors Wilder's reference to the Permian and the strata are so considered in this report.

The only beds sufficiently indurated to merit consideration as a possible source of structural materials belong to the gypsum itself. In the early history of the county quarries were opened in the gypsum beds which outcrop along the Des Moines river below Fort Dodge and the natural stone was used for foundation purposes and even to construct the walls of buildings by the pioneer settlers of the county. Some of these old buildings still stand and the walls are in a fair state of repair. It was soon found, however, that the stone was too soft and too easily dissolved in meteoric water to warrant its general use in important structures. At the present time while its use as a building stone has been abandoned it is being developed extensively for the manufacture of hard wall plasters, calcimines, Plaster of Paris and as a mineral paint.

The Cretaceous.

The Cretaceous system is represented in Iowa by rather loosely aggregated sandstones, clay-shales and marly limestones. The sandstones are prevailingly calcareous. Occasionally they are sufficiently indurated to merit consideration as a source of structural materials. This is notably true in Woodbury county where the stone was developed formerly and sold as "Sioux City Granite." No commercial quarrying is being done at the present time on account of the excessive overburden.

The calcareous deposits have been explored to some extent but with slight promise of future development. The marl and chalk beds attracted some attention at one time as a possible source of material suitable for the manufacture of Portland cement. The thinness and patchy character of the beds, and the heavy overburden are considered sufficient to indefinitely postpone the development of the beds.

CALHOUN COUNTY.

Imperfectly indurated beds belonging to the Cretaceous are known to outcrop along Lake creek, about one and a half miles northwest of Lake City. Similar beds are reported to outcrop along the Coon river in the southwestern portion of the county. Near the plant of the Lake City Brick and Tile Company, the following section may be observed:

		FEET.
5.	Drift and wash	10
4.	Shale, somewhat fissile, grayish blue to dark blue, dries a light gray-blue	4
3.	Sandstone, friable, in three ledges of about equal thickness; the lower ledge ferruginous and concretionary; the middle layer unindurated, white; the top layer stained a variable yellow	2
2.	Shale, clayey, mixed, not laminated; variable	7
1.	Sandstone, ferruginous and concretionary, exposed above bed of creek	5

Only the concretionary portions of the sandstones are sufficiently indurated for structural purposes. The clay-shale is rather siliceous and might be used in the manufacture of Portland cement when blended with limestone similar to that exposed in Humboldt and Pocahontas counties. The heavy overburden and absence of transportation facilities detract from its attractiveness as a commercial proposition. The analysis of the clay-shale is as follows:

Silica	74.83
Alumina	12.20
Ferric oxide	1.24
Lime	2.22
Magnesia	1.08
Potash	0.32
Soda	1.08
Sulphur trioxide	2.00
Loss on ignition	5.15
Moisture at 100°C	0.58
Total	100.70

J. B. WEEMS, Analyst.

CASS COUNTY.

Although but few exposures are known, the gravels, sandstones, and clays of the Nishnabotna sub-stage of the Dakota probably occupy considerable areas in Cass county. The sandstone is, as a rule, friable and the grains are not sufficiently well cemented to make it of value for building purposes. Directly south of the town of Lewis in section 15 of Cass township, and to the east of the river, is an outcrop in which the sandstone is of a fairly firm texture and from which large amounts have been removed, to be used locally. It is composed largely of fine, even grains of sand, with occasional larger fragments of limestone, partially cemented together with iron oxide. Small mica scales are scattered through it. While the stone is tender and requires careful handling on first exposure, it is said to harden very materially on drying, and with age. The sandstone breaks somewhat irregularly, but as readily in one direction as in another. Eight to twelve feet of the rock are exposed. So far as known, this is the only locality in the county where the Dakota beds afford a quarry product.

GUTHRIE COUNTY.

Suitable materials for building purposes are to be had from the Cretaceous strata, which supply unlimited quantities of sandstone and which are available over the western two-thirds of the county. These are, however, fit for local, rough work only, as they are in general but partially consolidated and will endure neither much handling nor shaping. The sandstone has been quarried on a small scale at many points in the county, particularly along the Raccoon and its branches in the vicinity of Glendon, in Plover township. Both the conglomerate and sandstone are quite commonly employed in foundations for farm buildings.

POTTAWATTAMIE COUNTY.

Strata belonging to the Cretaceous system underlie portions of Pottawattamie county east of the West Nishnabotna river. They consist of beds of clay and soft, friable sandstone, the latter varying in color from white to gray and brown. The entire county is deeply covered with Pleistocene deposits and the only evidence of the presence of the Cretaceous comes from deep wells and a few scattering exposures near the extreme southeast corner of the county.

J. A. Udden[*] records a maximum thickness of forty-two feet of Cretaceous sandstone occurring in the northeast quarter of section 36, Wright township, as an escarpment over a quarter of a mile in length, facing the river. It is again seen near the southeast corner of section 1 of this same township, also in section 28 of Grove township. In all instances, the rock is of uniform fine texture, but the grains of sand are poorly cemented so that it will usually crumble in the hand. Bedding is not conspicuous, great thicknesses appearing as one continuous ledge. All the exposures noted are heavily covered with glacial deposits. Aside from being the source of local supplies of good sand, the Cretaceous sandstones of this county are of little economic value.

PLYMOUTH AND WOODBURY COUNTIES.

The Cretaceous beds in Plymouth and Woodbury counties comprise an extensive and somewhat complicated series of sandstones, shales and limestones. The limestones often present a marly facies and are practically confined to the upper portion of the Cretaceous, the Benton sub-stage. The principal calcareous member of the Cretaceous in this locality was named *The Inoceramus Beds* by White.[*] Later, the beds were referred to the Niobrara division of Meek and Hayden, but more recent studies show that they are to be correlated with *The Green Horn Limestone,* the middle division of the Benton group as it is developed in the Edgemont quadrangle, South Dakota. In the vicinity of Sioux City, the arenaceous beds are highly indurated in places and become quartzitic in character. They have been quarried to a limited extent, but the excessive overburden renders any extensive development of the beds commercially impossible. The calcareous beds are best exposed in Cedar Bluff and vicinity, near Westfield, and near LeMars. At all of the above places they are interbedded with shales and arenaceous deposits and usually overlain with a thick deposit of loess and glacial debris.

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[*] Geology of Pottawattamie county. Iowa Geol. Survey, Vol. XI, p. 237.

[*] Report on the Geol. Surv. of the State of Iowa, by Charles A. White, M. D., Vol. I, p. 293; Des Moines, 1870.

They attain a maximum thickness of about thirty feet and are sufficiently pure to be used in the manufacture of lime and Portland cement. The following partial analyses were made for the Survey:

	I.	II.
Calcium carbonate ($CaCO_3$)	83.70	94.39
Magnesium carbonate ($MgCO_3$)	2.48	0.70

I. Chalk rock from old quarries on Big Sioux river south of Westfield, Plymouth county.

II. Chalk rock from Deep creek northeast of LeMars, southwest quarter of section 2, America township, Plymouth county.

While the beds were formerly used in the manufacture of lime, the introduction of cheap limes of better grade from other localities has caused the abandonment of the industry. The great amount of stripping which must be done in order to develop the beds renders them unavailable under present conditions for the manufacture of Portland cement.

SAC COUNTY.

Stratified rocks outcrop at but a single point within the confines of the county so far as known at this time. At Grant City the Coon river impinges strongly against its south bank and uncovers a series of coarse-grained sandstones, clay-shales and chalk deposits, the assemblage aggregating forty or fifty feet in thickness and belonging to the Cretaceous system. Where exposed the sandstone is not sufficiently indurated to be useful as a structural material. The clay-shales are of good quality and are used in a small way in the manufacture of brick. The chalk was used formerly for the manufacture of lime, an industry which long since was abandoned. The clay-shales and chalk blended in the proper proportions would probably produce a mixture suitable for the manufacture of Portland cement. The smallness of the section and the inaccessibility of the beds make such use impossible.

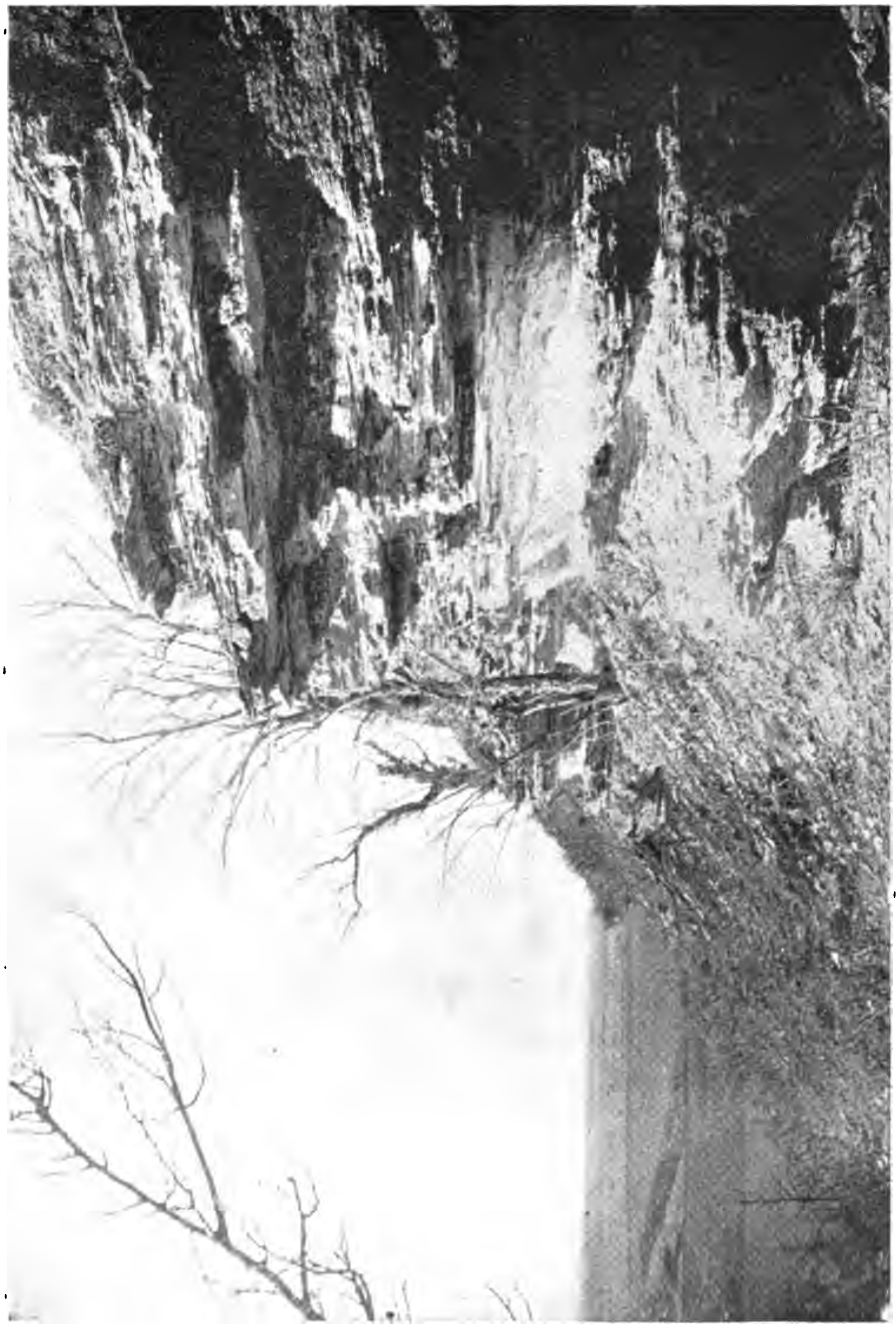

PLATE LXI—Chalk cliff on the Sioux river, Plymouth county.

The Pleistocene.

The various drift sheets supply a great variety of structural materials. Practically every great group of rocks save the volcanic is represented. The granitoid and gneissoid rocks are the predominant types. The Iowan drift area, especially, is rich in gigantic red and gray granites which have been and are being used extensively for structural purposes with excellent results. The high cost of working the bowlders into shapes suitable for building has been the chief factor against their general usage. In northwestern and western Iowa bowlders of the pink to red Sioux quartzite are common, but are usually of much smaller size than the granites of the Iowan.

Acknowledgments.

The writers have been the recipients of many courtesies from the quarrymen of the state, especially from those in charge of the commercial quarries.

The county reports have been freely used and oftentimes without mention in the text. The chapter on Cements, as previously stated, has been compiled largely from the paper by Eckel and Bain which appears in volume XV of these reports.

Most of the laboratory work on limes and cement materials was done by or under the immediate direction of the junior author of this report while the senior author assumes the major portion of the responsibility for the field work.

The Survey is fortunate in being able to include the chapter on Power Plants by Professor Bissell, which will undoubtedly prove a valuable reference work for commercial quarrymen.

The special tests of building stone, were made largely under the direction of Dean A. Marston.

The writers have had the advice and assistance of the officials of the Survey, especially the Director. The general geological section with notes prepared by Professor Calvin is an important contribution and aids greatly in understanding the sequence of the various quarry horizons. To these and to all who have in any way facilitated the work the authors take this occasion to acknowledge their obligations.

ANALYSES OF IOWA COALS.

County	Moisture	Volatile hydro-carbons	Fixed car-bon	Ash	Sulphur	Calorimetry B. T. U.
Adams—						
Average 6	8.76	34.22	45.12	11.89	3.60	....
Appanoose—						
Average 12	7.26	35.87	47.67	9.20	3.75	....
Centerville	11.49	33.47	48.56	6.52	2.92	12681
Mystic	16.21	32.74	46.00	5.05	2.64	12780
Boone—						
Average 6	6.82	40.99	44.45	7.74	4.01	....
Crowe Coal Co	4.03	39.79	48.30	7.88	3.99	12729
Street Railway Power Plant	11.49	26.33	37.83	24.36	9.53	....
Dallas—						
Average 8	8.25	35.11	42.17	14.47	4.24	....
Davis—						
Average 5	2.95	41.82	44.47	10.66	6.07	....
Bloomfield	5.24	37.00	50.66	7.10	2.25	13204
Greene—						
Average 4	9.01	42.11	42.03	6.86	3.37	....
Guthrie—						
Average 7	7.41	35.82	42.18	14.59	6.08	....
Jasper—						
Average 4	7.40	37.64	43.17	11.08	3.46	....
Colfax	5.45	40.49	46.97	7.09	2.91	12134
Keokuk—						
Average 6	6.11	39.43	44.39	10.07	6.36	....
Lucas—						
Average 5	9.40	37.65	44.08	8.87	3.34	....
Mahaska—						
Average 7	4.29	43.04	44.56	8.11	4.38	....
Marion—						
Average 4	6.17	37.79	49.27	6.78	....	....
Monroe—						
Average 8	5.55	40.38	44.42	9.65	5.21	....
Hocking (Mine No. 3)	6.63	38.37	40.88	14.12	6.92	....
Hocking (Mine No. 2)	5.80	42.56	42.71	9.03	3.75	12560
Hilton	6.51	37 97	45.07	10.45	3.02	12396
Buxton No. 10	9.48	35.58	46.07	10.87	2.06	12030
Buxton No. 9	6.19	43.60	42.30	5.91	3.45	....
Polk—						
Average 5	6.43	38.84	44.77	11.96	4.87	....
Marquisville	5.09	43.30	47.73	3.88	2.60	10574

ANALYSES OF IOWA COALS—CONTINUED.

County	Moisture	Volatile hydro-carbons	Fixed car-bon	Ash	Sulphur	Calorimetry B. T. U.
Scott—						
Average 6	3.61	39.95	47.13	9.29	4.71	....
Taylor—						
Average 5	5.93	36.17	44.54	11.34	4.85	....
Van Buren—						
Average 3	8.10	40.01	47.43	4.45	....	....
Wapello—						
Average 11	5.42	38.73	45.25	10.60	5.85	....
Pekay	9.98	41.46	42.21	6.35	2.53	13050
Laddsdale	4.23	40.92	45.76	9.09	4.75	13141
Warren—						
Average 4	10.60	38.26	43.75	7.36	4.44	....
Wayne—						
Average 4	9.01	34.48	43.43	13.07	3.84	....
Webster—						
Average 10	7.83	37.23	43.42	11.52	5.08	....
Lehigh	17.47	31.35	39.59	11.59	4.87	....

ANALYSES OF IOWA COALS.

County	Moisture	Volatile hydro-carbons	Fixed car-bon	Ash	Sulphur	Calorimetry B. T. U.
Adams—						
Average 6	8.76	34.22	45.12	11.89	3.60	......
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Average 5	9.40	37.65	44.08	8.87	3.34	......
Mahaska—						
Average 7	4.29	43.04	44.56	8.11	4.38	......
Marion—						
Average 4	6.17	37.79	49.27	6.78	......	......
Monroe—						
Average 8	5.55	40.38	44.42	9.65	5.21	......
Hocking (Mine No. 3)	6.63	38.37	40.88	14.12	6.92	......
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Hilton	6.51	37 97	45.07	10.45	3.02	12396
Buxton No. 10	9.48	35.58	46.07	10.87	2.06	12030
Buxton No. 9	6.19	43.60	42.30	5.91	3.45	......
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Wayne—						
Average 4	9.01	34.48	43.43	13.07	3.84	....
Webster—						
Average 10	7.83	37.23	43.42	11.52	5.08	....
Lehigh	17.47	31.35	39.59	11.59	4.87	....

ANALYSES OF LIMESTONES AND CHALKS.

ARRANGED ALPHABETICALLY BY COUNTIES.

Location and Description	Horizon	Composition						Authority
		Insoluble	Iron and alumina	Calcium carbonate	Magnesium carbonate	Sulphur trioxide	Moisture and organic matter	
APPANOOSE COUNTY—								
Rathbun	Des Moines	9.90	6.40	83.37	Trace	....	....	Lundteigen
BLACK HAWK COUNTY—								
Waterloo	Cedar Valley	1.92	4.20	63.59	30.92	....	....	C. E. Ellis
BREMER COUNTY—								
Waverly	Devonian	46.34	19.90	18.33	4.20	0.01	3.82	Lundteigen
Waverly	Devonian	2.25	1.32	88.65	6.70	....	0.35	Lundteigen
Waverly	Devonian	7.74	1.67	86.80	2.35	0.86	1.08	C. E. Ellis
Section 36—Douglas township	Niagara	1.53	0.48	54.32	43.41	....	0.26	N. Knight
Quarter section run	Wapsipinicon	0.71	....	96.57	1.80	....	0.51	N. Knight
Section 8—Polk township	Cedar Valley	3.28	2.12	55.23	39.08	....	0.39	N. Knight
CEDAR COUNTY—								
Cedar county	Otis	1.52	0.58	93.61	4.20	....	....	N. Knight
Rochester	Lower Davenport	0.86	0.30	96.91	1.93	....	....	N. Knight
Rochester	Lower Davenport	0.40	0.10	78.75	20.16	....	....	N. Knight
Rock Creek	Gower	0.12	0.26	55.76	43.85	....	....	N. Knight
Cedar Valley	Gower	0.40	0.70	56.40	42.60	....	....	N. Knight
Lime burning { Lime City	Gower	0.60	1.40	55.30	43.00	....	....	N. Knight
rock { Cedar Valley	Gower	0.23	0.35	51.27	48.09	....	....	N. Knight
Cedar Valley	Coggan	1.20	0.90	58.20	39.50	....	....	N. Knight
Cedar county	Otis	0.24	0.34	96.73	2.94	....	....	N. Knight
Cedar county	Wapsipinicon	18.66	2.00	58.21	21.00	....	....	N. Knight

ANALYSES OF LIMESTONES AND CHALKS.

ARRANGED ALPHABETICALLY BY COUNTIES.

Location and Description	Horizon	Composition						Authority
		Insoluble	Iron and alumina	Calcium carbonate	Magnesium carbonate	Sulphur tri-oxide	Moisture and organic matter	
CERRO GORDO COUNTY—								
Mason City	Cedar Valley	0.72	0.91	94.22	1.32	0.98	2.51	L. G. Michael
Mason City	Cedar Valley	0.63	0.71	97.48	0.99	....	0.51	A. O. Anderson
CLARKE COUNTY—								
Carpenter quarry, Osceola	Missouri	8.64	1.54	88.92	0.62	....	....	A. O. Anderson
Carpenter quarry, Osceola	Missouri	8.90	1.20	89.30	0.06	....	0.28	A. O. Anderson
Carpenter quarry, Osceola	Missouri	13.72	1.26	82.50	2.05	....	0.59	A. O. Anderson
DELAWARE COUNTY—								
Independence	Wapsipinicon	8.14	1.20	87.36	3.56	....	0.02	A. O. Anderson
DES MOINES COUNTY—								
Burlington	Osage	5.18	0.87	93.11	0.84	....	....	Geo. Steiger
DUBUQUE COUNTY—								
Cascade	Niagara	11.34	0.81	48.53	37.34	....	0.26	
Eagle Point—Lime burning rock	Galena	2.15	0.82	54.84	41.79	....	0.02	L. G. Michael
Eagle Point—Non-lime burning rock	Galena	8.63	0.85	51.52	39.52	....	0.04	L. G. Michael
Spechts Ferry—General sample	Platteville	5.00	2.07	89.64	1.72	0.85	....	Lundteigen
Spechts Ferry	Platteville	8.98	2.58	73.65	12.18	....	....	Lundteigen
Spechts Ferry	Platteville	7.28	1.27	83.77	5.42	0.39	....	Lundteigen
Spechts Ferry	Platteville	2.25	1.32	88.64	6.80	....	....	Lundteigen
Spechts Ferry	Platteville	7.50	6.17	79.50	3.97	1.48	0.15	L. G. Michael
Spechts Ferry	Platteville	7.94	12.05	73.38	3.52	1.69	0.10	L. G. Michael

Spechts Ferry	Platteville	10.71	6.69	78.67	0.28	1.51	0.15	L. G. Michael
Spechts Ferry	Platteville	11.24	6.31	78.51	0.24	1.58	0.10	L. G. Michael
Spechts Ferry	Platteville	5.74	6.69	83.56	0.25	1.77	0.10	L. G. Michael
Near Zollicoffer Lake, north of Dubuque	Platteville	8.28	4.67	80.14	2.37	2.60	0.13	L. G. Michael
Near Zollicoffer Lake, north of Dubuque	Platteville	8.02	5.78	77.93	4.43	0.22	0.16	L. G. Michael
Near Zollicoffer Lake, north of Dubuque	Platteville	6.79	4.61	78.24	5.12	1.74	0.04	L. G. Michael
Near Zollicoffer Lake, north of Dubuque	Platteville	3.85	6.03	84.16	1.93	0.64	1.71	L. G. Michael
Near Zollicoffer Lake, north of Dubuque	Platteville	4.54	2.54	86.33	3.54	0.22	0.08	L. G. Michael
Near Zollicoffer Lake, north of Dubuque	Platteville	3.26	0.83	90.20	2.65	1.64	0.06	L. G. Michael
FAYETTE COUNTY—								
Clermont	Maquoketa	11.95	2.80	84.80	0.45	....	....	L. G. Michael
Wilkes Williams' quarry, six miles south of Postville	Hopkinton	8.65	0.66	58.13	32.18	....	....	A. O. Anderson
Wilkes Williams' quarry, six miles south of Postville	Hopkinton	8.50	5.37	41.16	45.18	....	....	A. O. Anderson
Wilkes Williams' quarry, six miles south of Postville	Hopkinton	9.00	3.00	52.12	36.05	....	....	A. O. Anderson
Wilkes Williams' quarry, six miles south of Postville	Hopkinton	10.64	1.06	50.03	38.50	....	....	A. O. Anderson
Wilkes Williams' quarry, six miles south of Postville	Hopkinton	9.52	3.10	52.14	35.72	....	....	A. O. Anderson
Auburn	Hopkinton	0.68	0.50	98.52	....	....	....	L. G. Michael
HAMILTON COUNTY—								
Webster City	Saint Louis	1.60	0.80	92.85	5.31	....	....	A. O. Anderson
HUMBOLDT COUNTY—								
Humboldt	Kinderhook	0.50	1.12	97.20	2.00	....	....	A. O. Anderson
Near Gilmore	Kinderhook	....	....	99.62	....	....	....	J. B. Weems
Humboldt	Saint Louis	0.91	1.21	97.98	....	....	....	Murray
JACKSON COUNTY—								
Maquoketa	Hopkinton	0.58	0.36	30.88	21.56	....	....	C. E. Ellis
Maquoketa	Hopkinton	0.51	0.47	30.56	21.54	....	....	C. E. Ellis

ANALYSES OF LIMESTONES AND CHALKS.

ARRANGED ALPHABETICALLY BY COUNTIES.

Location and Description	Horizon	Composition						
		Insoluble	Iron and alumina	Calcium carbonate	Magnesium carbonate	Sulphur trioxide	Moisture and organic matter	Authority
JOHNSON COUNTY—								
Iowa City....................	Cedar Valley..........	3.08	1.97	89.79	4.66	0.06	....	Geo. Steiger
JONES COUNTY—								
J. A. Green, Stone City........	Gower, Anamosa......	0.97	0.42	57.19	41.44	....	....	A. O. Anderson
J. A. Green, Stone City........	Gower, Anamosa......	2.00	1.20	56.00	40.98	....	....	A. O. Anderson
J. A. Green, Stone City........	Gower, Anamosa......	4.46	1.70	56.08	37.80	....	....	A. O. Anderson
J. A. Green, Stone City........	Gower, Anamosa......	0.20	0.72	56.57	42.59	....	....	A. O. Anderson
J. A. Green, Stone City........	Gower, Anamosa......	1.20	0.50	58.86	39.58	....	....	A. O. Anderson
J. A. Green, Stone City........	Gower, Anamosa......	1.88	1.02	51.64	44.76	....	....	A. O. Anderson
J. A. Green, Stone City........	Gower, Anamosa......	0.96	0.72	63.56	34.76	....	....	A. O. Anderson
J. A. Green, Stone City........	Gower, Anamosa......	0.78	0.54	52.12	46.98	....	....	A. O. Anderson
J. A. Green, Stone City........	Gower, Anamosa......	1.13	1.50	58.21	38.60	....	....	A. O. Anderson
Dearborn & Sons, Stone City ..	Gower, Anamosa......	1.97	0.89	55.68	41.53	....	....	A. O. Anderson
Dearborn & Sons, Stone City ..	Gower, Anamosa......	2.05	0.37	54.64	43.35	....	....	A. O. Anderson
Dearborn & Sons, Stone City ..	Gower, Anamosa......	1.70	0.60	55.70	41.74	....	....	A. O. Anderson
Dearborn & Sons, Stone City ..	Gower, Anamosa......	1.90	1.43	56.60	39.97	....	....	A. O. Anderson
Dearborn & Sons, Stone City ..	Gower, Anamosa......	2.00	0.40	55.18	41.70	....	....	A. O. Anderson
LOUISA COUNTY—								
Morning Sun....................	....	1.60	1.20	97.02	0.32	....	....	A. O. Anderson

MADISON COUNTY—								
Earlham	Bethany	7.85	1.00	91.15	0.61			L. G. Michael
Peru	Bethany	17.16	2.64	72.76	2.86	0.95	0.30	L. G. Michael
Earlham	Missouri	10.92	2.37	84.87	1.58			Geo. Steiger
Winterset	Missouri	12.63	1.18	84.34	2.19		0.02	A. O. Anderson
MAHASKA COUNTY—								
Oskaloosa	Saint Louis	4.01	0.59	95.30				Murray
MARION COUNTY—								
Tracy	Saint Louis	1.57	0.66	94.60	6.66			Murray
Pella	Saint Louis	4.92	3.39	84.39				Lundteigen
MARSHALL COUNTY—								
Oölite. Quarry	Kinderhook	0.77	0.18	98.30	0.59		0.16	G. E. Patrick
Blue limestone. Quarry	Kinderhook	0.96	0.41	97.95	0.38		0.30	G. E. Patrick
Iowa caen stone. Quarry	Kinderhook	1.24	0.50	90.28	7.77		0.21	G. E. Patrick
Stratified limestone. Quarry	Kinderhook	1.22	0.50	90.04	8.08		0.16	G. E. Patrick
MITCHELL COUNTY—								
Osage	Cedar Valley	0.78	0.12	98.01	0.15			A. O. Anderson
Osage	Cedar Valley	0.12	0.12	98.01	0.15		0.35	A. B. Hoen
Osage	Cedar Valley	2.21	3.82	90.17	1.03		2.63	A. O. Anderson
MONTGOMERY COUNTY—								
Stennett	Missouri	7.97	1.26	89.44	1.92			A. O. Anderson
PLYMOUTH COUNTY—								
Chalk rock, Westfield	Cretaceous			83.70	2.48		0.08	J. B. Weems
Chalk rock, Le Mars	Cretaceous			94.39	0.70		0.06	J. B. Weems
SCOTT COUNTY—								
Bettendorf	Wapsipinicon	4.46	0.70	79.60	15.40			C. E. Ellis
Le Claire Stone Co., Bettendorf	Wapsipinicon	2.36	2.20	94.57	0.81			C. E. Ellis
Le Claire Stone Co., Bettendorf	Wapsipinicon	0.54	0.14	98.49	0.72			C. E. Ellis
Bettendorf	Wapsipinicon	1.04	0.28	90.00	8.36			C. E. Ellis
Bettendorf	Wapsipinicon	8.48	0.72	89.25	1.42			C. E. Ellis
Bettendorf	Wapsipinicon	26.40	9.25	44.82	10.84		8.82	C. E. Ellis
Bettendorf	Wapsipinicon	16.08	3.26	49.72	29.06		1.86	C. E. Ellis

ANALYSES OF LIMESTONES AND CHALKS.

ARRANGED ALPHABETICALLY BY COUNTIES.

Location and Description	Horizon	Composition						Authority
		Insoluble	Iron and alumina	Calcium carbonate	Magnesium carbonate	Sulphur trioxide	Moisture and organic matter	
SCOTT COUNTY—CON.								
Bettendorf	Wapsipinicon	5.98	0.30	90.91	2.77	....	....	C. E. Ellis
Bettendorf	Wapsipinicon	1.32	0.38	76.23	22.21	....	....	C. E. Ellis
Bettendorf	Wapsipinicon	1.10	0.34	80.95	17.68	....	....	C. E. Ellis
Bettendorf	Wapsipinicon	1.20	1.08	97.32	0.76	....	....	C. E. Ellis
Le Claire Stone Co., Le Claire.	Gower, Anamosa	4.76	1.22	58.72	35.38	....	....	A. O. Anderson
Le Claire Stone Co., Le Claire.	Gower, Anamosa	7.44	1.37	51.55	40.36	....	....	A. O. Anderson.
Le Claire Stone Co., Le Claire.	Gower, Anamosa	5.60	1.40	53.96	39.00	....	....	A. O. Anderson
Le Claire Stone Co., Le Claire.	Gower, Anamosa	7.08	1.24	53.17	35.03	....	....	A. O. Anderson
SIOUX COUNTY—								
Hawarden	Cretaceous	21.92	6.68	64.30	5.38	....	....	Newberry
TAYLOR COUNTY—								
Fred Andrews, Bedford	Missouri	1.80	3.20	93.56	1.54	....	....	A. O. Anderson
Fred Andrews, Bedford	Missouri	1.48	0.48	97.42	1.14	....	....	A. O. Anderson
Fred Andrews, Bedford	Missouri	1.20	0.70	96.96	1.28	....	....	A. O. Anderson
VAN BUREN COUNTY—								
West of Farmington	Saint Louis	10.14	0.90	88.73	0.38	....	0.15	C. E. Ellis
Chequest creek, Keosauqua	Saint Louis	3.12	1.38	94.81	0.52	....	0.26	A. O. Anderson
Upper twenty feet of limestone. East of Bentonsport	Saint Louis	5.28	0.52	93.34	1.00	....	0.20	C. E. Ellis

WAPELLO COUNTY—								
Ottumwa	Saint Louis	6.83	2.66	88.43	0.15	0.13	....	Geo. Steiger
WINNESHIEK COUNTY—								
Decorah	Galena	14.53	6.49	72.89	1.03	0.48	0.15	L. G. Michael
Decorah	Galena	3.86	2.54	91.19	0.84	....	0.05	L. G. Michael
Decorah	Galena	6.87	1.00	88.97	2.86	....	0.30	C. E. Ellis

ANALYSES OF CLAYS, SHALES AND MARLS.

ARRANGED ALPHABETICALLY BY COUNTIES.

Locality and Description	Horizon	Composition										Authority
		Silica SiO_2	Alumina Al_2O_3	Ferric Oxide Fe_2O_3	Lime CaO	Magnesia MgO	Sulphur trioxide SO_3	Potash K_2O	Soda Na_2O	Loss on ignition	Moisture	
CERRO GORDO COUNTY—												
Mason City..............	Lime Creek...	54.64	14.62	5.69	5.16	2.90	......	4.77	1.12	8.54	0.85	G. E. Patrick
Clay Banks near Portland.	Lime Creek...	49.93	20.23	4.32	6.70	2.79	1.14	2.25	2.17	3.29	1.21	J. B. Weems
Clay Banks near Portland.	Lime Creek...	50.15	19.68	4.08	9.78	2.26	1.18	1.62	1.03	0.76	1.00	J. B. Weems
Clay Banks near Portland.	Lime Creek...	20.26	11.28	2.76	31.42	3.44	2.09	1.09	0.50	2.72	0.73	J. B. Weems
Clay Banks near Portland.	Lime Creek...	5.36	3.79	1.20	48.18	2.70	1.02	0.46	0.27	0.17	0.35	J. B. Weems
Clay Banks near Portland.	Lime Creek...	20.82	11.55	2.76	30.01	4.01	1.19	1.41	0.72	3.67	0.75	J. B. Weems
Clay Banks near Portland.	Lime Creek...	7.59	5.62	1.56	44.34	3.22	0.51	0.48	0.29	2.44	0.68	J. B. Weems
Clay Banks near Portland.	Lime Creek...	27.26	19.15	4.32	16.47	2.23	1.11	2.20	1.55	2.04	0.93	J. B. Weems
Mason City..............	Lime Creek...	51.95	18.34	7.56	4.14	3.26	2.76	4.12	......	7.49	0.42	J. B. Weems
Mason City..............	Lime Creek...	54.61	14.62	6.45	9.21	6.09	......	5.89	......	3.74	0.85	G. E. Patrick
CLARKE COUNTY—												
Osceola..................	Missouri......	55.52	14.51	9.09	5.00	2.60	0.28	1.50	1.32	8.28	1.39	C. E. Ellis
CLAYTON COUNTY—												
St. Sebald...............	Maquoketa ...	52.29	20.64	5.16	1.89	1.12	......	2.77	8.27	2.76	......	J. B. Weems
Edgewood...............	Maquoketa ...	44.39	13.72	7.80	7.88	6.05	......	1.56	5.29	......	0.89	J. B. Weems
Edgewood, Sperry Twp...	Maquoketa ...	52.29	20.64	5.16	1.89	1.12	......	2.77	8.27	5.17	......	J. B. Weems
Edgewood, Newberry Park	Maquoketa ...	44.39	13.72	7.80	7.88	6.05	......	1.56	5.29	12.18	0.89	J. B. Weems
DALLAS COUNTY—												
Van Meter...............	Des Moines...	86.63	10.92	0.10	......	......	......	......	......	2.32	......	W. S. Robinson

Des Moines County—												
Danville	Des Moines	74.82	15.54	2.72	0.73	0.45	......	0.32	0.38	4.97	0.22	J. B. Weems
Dubuque County—												
Spechts Ferry	Platteville	54.90	25.50	......	0.41	0.30	......	9.55		9.10	......	Lundteigen
Spechts Ferry	Platteville	49.32	20.16	8 30	5.33	1.53	......	4.68	......	4.82	0.72	L. G. Michael
North of Dubuque	Platteville	50.22	12.45	9.08	7.75	1.40	1.16	5.23	......	3.81	1.71	L. G. Michael
Graf	Maquoketa	42.53	16.83	5.66	5.66	4.82	......	3.70	4.10	15.76	......	J. B. Weems
Fayette County—												
Auburn	Maquoketa	49.60	6.36	6.25	22.45	0.20	......	0.90	0.35	13.56	......	L. G. Michael
Clermont Brick & Tile Co.	Maquoketa	28.82	10.37	3.76	19.14	5.40	......	5.38	7.41	16.24	0.43	J. B. Weems
Floyd County—												
Rockford	Lime Creek	50.40	......	31.22	4.30	2.74	1.54	4.96	......	4.51	0.41	L. G. Michael
Guthrie County—												
Panora	Des Moines	53.82	17.53	5.65	4.40	2.19	3.34	1.74	1.12	8.29	2.62	C. E. Ellis
Glendon	Missouri	48.91	17.66	6.62	8.42	1.90	0.28	2.61	1.44	10.23	1.60	C. E. Ellis
Guthrie Center	Des Moines	68.62	14.98	4.16	1.48	1.09	......	1.50	1.86	3.55	2.78	G. E. Patrick
Hardin County—												
Eldora Pipe & Tile Co.	Des Moines	72.09	16.24	1.08	0.48	0.48	0.14	1.08	0.77	5.18	2.46	C. E. Ellis
Lee County—												
Belfast	Osage	45.00	16.68	3.86	10.04	3.69	2.26	1.96	1.16	15.02	0.48	C. E. Ellis
Madison County—												
Winterset	Missouri	26.72	3.83	3.11	36.08	0.48	0.22	1.12	0.18	28.40	0.55	C. E. Ellis
Polk County—												
Des Moines	Des Moines	63.75	19.78	5.75	1.55	1.22	......	0.54	1.20	2.92	......	J. B. Weems
Des Moines	Des Moines	61.36	22.12	6.07	1.90	0.80	......	1.22		4.52	......	L. G. Michael
Des Moines	Des Moines	55.56	21.33	10.56	1.59	2.94	......	......	......	4.65	0.97	C. O. Bates
Des Moines	Des Moines	64.41	20.43	5.88	0.34	1.71	......	......	1.90	3.93	1.27	C. O. Bates
Scott County—												
Pleasant Valley	Des Moines	64.74	17.98	5.38	0.00	0.60	0.58	1.73	0.45	7.48	1.70	C. E. Ellis
Pleasant Valley	Des Moines	72.20	15.44	2.10	1.32	0.00	0.55	0.31	2.83	5.23	0.40	C. E. Ellis
Le Claire Stone Co., Davenport	Des Moines	71.90	12.64	2.20	1.70	1.34	2.68	2.64	Trace	4.23	1.10	C. E. Ellis

ANALYSES OF CLAYS, SHALES AND MARLS.

ARRANGED ALPHABETICALLY BY COUNTIES.

Locality and Description	Horizon	Composition										
		Silica SiO_2	Alumina Al_2O_3	Ferric Oxide Fe_2O_3	Lime CaO	Magnesia MgO	Sulphur tri-oxide SO_3	Potash K_2O	Soda Na_2O	Loss on ignition	Moisture	Authority
VAN BUREN COUNTY—												
Farmington...	Osage..	35.48	15.85	5.43	12.56	6.24	3.36	1.59	0.26	17.14	1.88	A. O. Anderson
WAPELLO COUNTY—												
Ottumwa..................	Des Moines...	53.86	26.28	4.32	0.12	0.43	......	2.52	0.43	11.08	......	J. B. Weems
WEBSTER COUNTY—												
Fort Dodge...............	Des Moines...	67.96	21.64	1.12	0.51	0.67	0.44	......	......	......	7.27	C. E. Ellis
Kalo.....	Des Moines...	70.20	16.70	4.00	0.28	0.63	0.82	1.75	1.39	3.70	0.53	J. B. Weems
Lehigh Clay Works, Lehigh	Des Moines...	53.08	17.71	8.64	4.05	0.94	......	1.25	3.70	9 30	......	J. B. Weems
Fort Dodge Pottery Co...	Des Moines...	66.00	19.32	0.80	2.85	0.54	......	1.15	2.49	6.84	......	J. B. Weems

Tests of Iowa Building Stones

BY

A. MARSTON

TESTS OF IOWA BUILDING STONES.

The tests compiled in tables I to VI inclusive include those made during the present investigation and also those which appear in the earlier reports of the present Survey. In general the materials were collected by a member of the Survey, but the majority of the tests were made under the direction and supervision of Professor A. Marston, Dean of the Engineering division of the Iowa State College, Ames, Iowa. Tables I and II include the transverse tests made upon much larger blocks than are ordinarily used for the purpose. The dimensions and distances between supports are given in the tables. The crushing tests recorded in table III were made on cubes approximating two inches. The absorption tests of the present investigation were carried through a much longer period than is usually done although at the end of 700 hours the specimens had not yet reached a constant weight. Tables V and VI give the results of two investigations, neither of which was carried far enough to be conclusive. The only conclusion which can be drawn safely is that twenty freezings and thawings have no appreciable effect, either in decreasing the strength or in increasing the disintegration of the materials tested.

In several of the tables, tests of building stone from other states which enter the Iowa markets in competition with the Iowa products were included for comparison.

TABLE I.

TRANSVERSE TESTS* OF ORIGINAL SPECIMEN.

Number of specimen	Height	Width	Total Length	Distance of Fracture from Nearer Support	Description of Fracture	Breaking Load in Pounds	Lbs. Per Square Inch
	Inches	Inches	Inches	Inches			Modulus of rupture
1	4.78	6.08	24	9	Marked by crystals of calcite	....	....
2	4.90	6.22	24	8.5	Fairly regular.........	3490	636
3	4.82	5.90	24	8.75	Fairly regular.........	3530	701
4	5.00	5.92	25	8.62	Very regular	5110	938
5	7.18	8.00	22.25	8.5	Very regular	11180	735
6	7.32	7.30	27	9	Very regular	6480	451
7	6.96	7.30	27.5	6.5	Fairly regular.........	5150	397
8	7.20	7.47	28.5	7.5	Fairly regular.........	6770	476
9	7.24	7.81	28	7.5	Fairly regular.........	5880	390
10	6.14	7.45	27.75	6	Fairly regular.........	4210	409
11	7.22	6.57.	28	6.5	Regular...............	6400	508
12	7.24	7.65	27	8.75	Very regular	6730	457
13	6.86	7.32	28.75	7.5	Fairly regular.........	5130	406
14	6.71	7.52	26	8	Fairly regular.........	5910	475
15	6.50	7.30	26.5	8	Fairly regular.........	8560	754
16	6.50	7.42	26.5	7.75	Fairly regular.........	8000	693
17	6.48	7.34	28	8.5	Very regular	9110	802
18	6.40	7.03	27.5	8.5	Fairly regular.........	7470	705
19	6.40	8.17	27	8.75	Fairly regular.........	10480	850
20	6.06	6.86	24.5	8.25	Very regular	8840	952
21	6.15	6.48	25.5	8.75	Fairly regular.........	8210	909
22	7.09	6.90	25.5	8.5	Fairly regular.........	9090	711
23	6.08	6.94	25.5	8.75	Very regular	8850	936
24	7.13	7.30	25.5	8.5	Fairly regular.........	10940	800
25	6.00	6.00	24	7.7	Fairly regular.........	9390	1178
26	5.98	5.98	24	9	Fairly regular.........	8940	1133
27	5.98	5.98	24	8.5	Fairly regular.........	8620	1093
28	5.92	5.90	24	8.75	Fairly regular....... .	2550	337
29	5.92	5.96	24	8.25	Fairly regular.........	2720	356
30	5.96	5.91	24	8.5	Fairly regular.........	5080	658
31	6.20	6.20	24	8	Fairly regular.........	8180	931
32	5.92	5.97	24	8.5	Fairly regular.........	6100	791

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* 18 inch supports.

Numbers 1-5 are dolomites from the Wilkes Williams quarry about six miles south of Postville, Iowa.

Numbers 6-14 are from Senator J. A. Green's quarry, Stone City, Iowa.

Numbers 15-19 are from the quarry of Dearborn & Sons, Stone City, Iowa.

Numbers 20-24 were furnished by the LeClaire Stone Company, Davenport, Iowa.

Numbers 25 and 26 represent blue Bedford oölite and 27 and 31 buff Bedford stone.

Numbers 28-30 represent Lake Superior in red sandstone.

Number 32 is Cleveland sandstone.

The same numbers are used in tables II and VI.

TABLE II.

TRANSVERSE TESTS* OF LONGER PIECE OF SPECIMEN AFTER FIRST TEST.

Number of specimen	Height	Width	Length of Span	Fracture	Failure	Lbs. Per Square Inch
	Inches	Inches	Inches			Modulus of rupture
1	4.78	6.12	10	Marked by crystals of calcite.....	6540	702
2	4.88	6.22	10	Fairly regular....................	8000	811
3	4.82	5.88	10	Fairly regular....................	4800	527
4	5.00	5.92	10	Very regular......................	10600	1074
5	7.44	7.03	8	Very regular......................	21520	664
6	7.25	7.41	10	Very regular......................	17660	680
7	7.10	7.22	10	Regular	16440	677
8	7.26	7.32	10	Large calcite crystals, regular....	17740	690
9	7.16	7.80	10	Fairly regular......	14000	525
10	6.10	7.59	10	Very regular......................	16290	867
11	6.60	6.81	10	Very regular......................	16200	809
12	7.14	7.31	10	Regular	18820	757
13	7.30	6.53	10	Very regular......................	12000	517
14	7.08	7.43	10	Very regular......................	18770	758
15	6.54	8.18	10	Very regular......................	18000	772
16	6.56	7.42	10	Very regular......................	21180	1003
17	6.54	7.58	10	Fairly regular....................	19180	887
18	6.52	7.19	10	Regular	17630	865
19	6.52	8.04	10	Fairly regular....................	21870	960
20	6.28	7.06	10	Very regular......................	17930	966
21	6.10	6.55	10	Fairly regular....................	21380	1312
22	6.81	7.00	10	Very regular......................	20000	924
23	6.12	7.00	10	Regular	22000	1260
24	7.13	6.54	10	Fairly regular....................	17140	773
25	6.20	6.00	10	Fairly regular....................	8000	1170
26	5.97	5.97	10	Fairly regular....................	14950	1054
27	5.98	5.98	10	Fairly regular....................	13470	942
28	5.90	5.86	10	Fairly regular....................	4420	325
29	5.94	5.95	10	Fairly regular....................	4920	351
30	5.94	5.88	10	Fairly regular....................	8980	649
31	6.20	6.20	10	Fairly regular....................	13550	853
32	5.93	5.98	10	Fairly regular....................	10000	713

* 10 inch supports.

TABLE No. III.

CRUSHING TESTS OF IOWA BUILDING STONES.

County	Location of Quarry	Kind of Stone	Working area in inches	Load Per Square Inch		Authority	Remarks
				Spalling	Failure		
Dallas.......	Van Meter.....	Sandstone............	4.14	10,800	11,700	C. E. Dept.........	Seamy, Coal Measures
	Van Meter.....	Sandstone............	4.04	12,200	13,900	do	Seamy, Coal Measures
Delaware....	Hopkinton.....	Limestone.........	4.14	3,600	5,500	do	
			4.18	3,650	4,600	do	
			4.14	6,377	6,377	do	
Des Moines..	Burlington	Limestone	3.01	6,500	6,600	do	John Loftus quarry
	Burlington	White limestone	4.00	6,800	8,500	do	John Loftus quarry
	Burlington	Gray limestone	4.28	6,700	13,100	do	John Loftus quarry
	Burlington	Blue limestone.......	3.50	6,700	11,400	do	John Loftus quarry
Fayette	Six miles south of Postville ..	Dolomite......	4.01	2,392	4,520	do	Wilkes Williams quarry { All sheared vertically
	Six miles south of Postville ..	Dolomite....	3.86	3,625	4,620	do	
	Six miles south of Postville ..	Dolomite.........	3.93	4,270	5,810	do	
	Six miles south of Postville ..	Dolomite....	3.98	1,207	3,252	do	
	Six miles south of Postville ..	Dolomite.........	4.05	1,198	2,470	do	
Humboldt...	Humboldt.	Limestone...	3.82	5,500	6,200	do	Saint Louis limestone

Jasper.......	Monroe........	Sandstone...........	4.36	3,600	3,600	do	Coal Measure sandstone E. G. Kemper quarry
	Monroe........	Sandstone...........	4.57	3,700	3,700	do	
Jones.	Hale....	Dolomite............	4.00	2,887	2,887	do	Sheared conically
	Hale....	Dolomite............	3.60	2,937	2,937	do	Sheared conically
	Hale	Dolomite............	3.33	3,067	4,375	do	Sheared conically
	Stone City	Dolomite............	3.95	1,519	2,987	do	J. A. Green quarries
	Stone City	Dolomite............	3.93	2,150	3,422	do	J. A. Green quarries
	Stone City.	Dolomite............	4.00	5,425	5,425	do	J. A. Green quarries
	Stone City.	Dolomite............	3.82	3,140	3,390	do	J. A. Green quarries
	Stone City.	Dolomite............	3.80	2,053	4,184	do	J. A. Green quarries
	Stone City.	Dolomite............	3.98	1,785	3,000	do	J. A. Green quarries
	Stone City.	Dolomite............	3.90	2,000	3,775	do	J. A. Green quarries
	Stone City.	Dolomite............	3.93	2,914	3,269	do	J. A. Green quarries
	Stone City.	Dolomite............	3.90	3,000	3,310	do	J. A. Green quarries
	Stone City	Dolomite............	3.79	2,290	3,600	do	Dearborn & Sons
	Stone City	Dolomite............	3.88	773	3,090	do	Dearborn & Sons
	Stone City	Dolomite............	3.81	3,753	3,753	do	Dearborn & Sons
	Stone City	Dolomite............	3.93	1,880	3,052	do	Dearborn & Sons
	Stone City	Dolomite............	3.85	2,910	3,300	do	Dearborn & Sons
	Stone City	Dolomite............	4.04	5,300	6,400	do	F. S. Brown & Co.
	Stone Ctty	Dolomite............	4.12	4,100	6,600	do	F. S. Brown & Co.
	Stone City.....	Dolomite............	4.06	6,100	7,400	do	J. A. Green { Strawboard bearings
	Stone City.....	Dolomite............	4.08	5,600	7,500	do	
	Stone City.....	Dolomite............	4.02	4,000	4,100	do	
	Stone City.....	Dolomite............	4.08	5,400	5,400	do	
	Stone City.....	Dolomite............	4.12	6,300	5,700	do	
	Stone City.....	Dolomite............	4.02	4,500	5,000	do	
	Stone City.....	Dolomite............	3.92	4,800	4,800	do	
	Stone City.....	Dolomite............	4.06	12,500	13,400	do	Dearborn & Sons "upper white"
	Stone City.....	Dolomite............	3.98	10,600	11,600	do	Dearborn & Sons "8-inch bed"
	Stone City.....	Dolomite............	4.16	6,700	6,700	do	Dearborn & Sons "flagging layer"
	Stone City.....	Dolomite	4.10	12,200	13,200	C. E. Dept..........	Dearborn & Sons, "dimension stone"
	Stone City.....	Dolomite	4.20	6,500	6,500	do	Dearborn & Sons, "bridgestone"

TABLE No. III—CONTINUED.

County	Location of Quarry	Kind of Stone	Working area in inches	Load Per Square Inch		Authority	Remarks
				Spalling	Failure		
Jones.......	Stone City.....	Dolomite	......	....	5,917	Col. D. W. Flagler..	Dearborn & Sons, "bridgestone"
	Stone City.....	Dolomite	......	....	11,250	Dodge, Minn. Geol. and Nat. History Survey............	J. A. Green
	Stone City.....	Dolomite	......	....	6,750	Dodge, Minn. Geol. and Nat. History Survey	J. A. Green, cube placed on edge
	Stone City.....	Dolomite	......	....	7,625	Lieut. W. P. Butler.	J. A Green
Lee	West Point.....	Brown sandstone.....	4.00	7,000	7,000	C. E. Dept..........	Craig Quarry No. 1: Broke with slight report and exhibited conical shears
	West Point.....	Brown sandstone.....	4.33	4,620	6,890	do	
	West Point.....	Brown sandstone.....	3.80	5,660	5,800	do	
	West Point.....	Gray sandstone......	3.40	5,830	7,650	do	Craig Quarry No. 2: Conical shear
	West Point.....	Gray sandstone......	3.80	4,740	6,530	do	Slightly inclined shear
	West Point.....	Gray sandstone......	4.04	3,710	7,180	do	Slightly inclined shear
Louisa	Morning Sun...	Limestone	3.61	3,950	3,950	do	Wilson quarry, all samples broke without report and reduced to a granular mass
	Morning Sun...	Limestone	3.72	3,360	3,360	do	
	Morning Sun...	Limestone	3.61	2,490	2,880	do	
Madison	Winterset......	Limestone	......	....	4,588	Rock Island Arsenal	Bevington quarry

Mahaska....	Given	Limestone	3.70	8,500	12,500	C. E. Dept.........	Saint Louis limestone
Marion......	Red Rock......	Red sandstone......	.....	....	4,434	L. Higgins..........	Coal Measure sandstone
	Tracy.........	Limestone	4.12	7,300	9,500	C. E. Dept..........	Saint Louis limestone
	Tracy.........	Limestone	4.20	5,200	9,900	do	Saint Louis limestone
Marshall....	Quarry	† Oölite	3.94	....	11,600	do	Failure, accompanied by much shattering
	Quarry	† Oölite	4.00	11,875	13,450	do	
	Quarry	† Oölite	3.96	13,636	14,900	do	
	Quarry	† Oölite	3.84	10,260	10,260	do	
	Quarry	Oölite...............	4.08	10,280	12,740	do	
	Quarry	Oölite...............	4.00	14,250	14,250	do	
	Quarry	Oölite...............	4.00	9,500	13,250	do	
	Quarry	† Iowa marble, plain.	3.90	....	12,080	do	All samples of Iowa marble broke in such a way as to show much elasticity
	Quarry	† Iowa marble, plain.	4.12	14,685	15,120	do	
	Quarry	† Iowa marble, colored	4.06	....	9,128	do	
	Quarry	Blue limestone.......	4.08	....	....	do	63,000 lbs. applied, no effect
	Quarry	Blue limestone.......	4.04	....	....	do	63,000 lbs. applied, no effect
	Quarry	Fossiliferous limestone..............	4.00	10,500	....	do	Sustained 65,800 lbs. without further rupture
	Quarry	Fossiliferous limestone....	4.00	15,825	....	do	Beyond capacity of machine to crush
	Quarry	Fossiliferous limestone	4.00	10,925	....	do	Sustained 65,800 lbs. without further rupture
	Quarry	Fossiliferous limestone..............	4.04	14,430	16,435	do	
	Quarry	Fossiliferous limestone..	3.96	9,773	9,773	do	
	Quarry	Blue limestone.......	3.96	7,070	8,712	do	
	Quarry	Blue limestone.......	3.96	7,320	8,383	do	
Scott........	LeClaire.......	Dolomite	4.16	11,100	....	do	Specimen from F. H. Thielman and stood 12,000 lbs. without crushing
	LeClaire.......	Dolomite	4.22	9,900	....	do	Specimen from F. H. Thielman and stood 13,300 lbs. without crushing
	LeClaire.......	Dolomite	3.85	2,920	7,630	do	LeClaire Stone Company
	LeClaire.......	Dolomite	3.80	1,965	5,720	do	LeClaire Stone Company, vertically sheared

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† Tests made under the direction of Prof. G. W. Bissell, Dept. of Mechanical Engineering, I. S. C.

TABLE No. III—CONTINUED.

County	Location of Quarry	Kind of Stone	Working area in inches	Load Per Square Inch		Authority	Remarks
				Spalling	Failure		
	LeClaire.......	Dolomite....	3.86	3,808	5,025	C. E. Dept.........	LeClaire Stone Co.......... Sheared vertically
	LeClaire.......	Dolomite....	4.00	3,000	7,775	do	
	LeClaire.......	Dolomite....	3.64	2,371	3,901	do	
Van Buren..	Chequest Creek	Gray sandstone......	4.20	3,740	3,880	do	Price quarry
	Chequest Creek	Gray sandstone......	4.20	5,740	5,740	do	Price quarry
	Chequest Creek	Gray sandstone......	3.80	4,630	5,200	do	Price quarry
	Chequest Creek	Gray sandstone......	4.18	6,030	6,030	do	Price quarry
	Chequest Creek	Gray limestone......	3.50	8,140	11,430	do	Price quarry, "fossiliferous"
	Chequest Creek	Gray limestone......	3.06	3,590	8,770	do	Price quarry, "fossiliferous"
	Chequest Creek	Gray limestone......	3.43	6,850	7,320	do	Price quarry, "fossiliferous"
	Chequest Creek	Limestone	3.76	3,370	4,520	do	Price quarry, "dimension stone"
	Chequest Creek	Limestone	3.80	2,760	2,770	do	Price quarry, "dimension stone"
	Chequest Creek	Limestone	4.00	1,750	4,275	do	Price quarry, "dimension stone"

TABLE No. III—CONTINUED.—STONE FROM COMPETING LOCALITIES OUTSIDE OF IOWA.

County	Location of Quarry	Kind of Stone	Working area in inches	Load Per Square Inch		Authority	Remarks
				Spalling	Failure		
Illinois	Joliet	Dolomite			14,775	Gilmore	Average of three tests
	Lemont	Dolomite			12,000	do	
Indiana	Bedford	Blue oölite	4.07	3,439	4,373	C. E. Dept	Stone from Fred Andrews
	Bedford	Blue oölite	3.91	5,626	5,626	do	Stone from Fred Andrews
	Bedford	Buff oölite	4.09	1,467	5,480	do	Stone from Fred Andrews
	Bedford	Buff oölite	4.12	6,050	6,050	do	Stone from Fred Andrews
Michigan	Lake Superior	Red sandstone	3.89	5,527	5,887	do	
	Lake Superior	Red sandstone	4.00	4,400	6,712	do	
	Lake Superior	Red sandstone	4.08	8,700	9,450	do	
Minnesota	Kasota	Dolomite			18,500	Gilmore	
	Winona	Dolomite			16,250	do	
Ohio	Berea	Sandstone			8,222	do	Average of four tests
	Cleveland	Sandstone	4.01	6,870	8,350	C. E. Dept	Stone from Fred Andrews

TABLE .

ABSORPTION TESTS SHOWING

County	Location of Quarry	Kind of Stone	Number of Hours in Water					
			1	8	24	48	72	144
Dallas......	Van Meter....	Sandstone	.....	.....	.....	.....	.....	.....
Des Moines.	Burlington. . .	Gray limestone	.....	.....	.....	.....	.....	.....
	Burlington. . .	White limestone ...	.....	.....	.....	.....	.....	.....
Fayette	Williams... ..	Dolomite	4.32	4.80	5.12	5.41	5.70	.....
	Williams.. ...	Dolomite	4.71	5.22	5.52	5.82	6.12	.....
	Williams.	Dolomite.	5.18	5.70	5.98	6.31	6.68	.....
	Williams... ..	Dolomite	4.53	5.08	5.33	5.62	5.92	.....
[redacted]	Williams.	Dolomite.	4.44	4.88	5.26	5.42	5.84	.....
Humboldt..	Humboldt. . .	St. Louis limestone	.....	.....	.....	.....	.....	.....
Jasper.	Monroe.......	Sandstone	.....	.....	.....	.....	.....	.....
Jones	Stone City....	Dolomite	.....	.....	.....	.....	.....	.....
	Stone City....	Dolomite..........	.....	.....	.....	.....	.....	.....
	Stone City....	Dolomite.	.....	.....	.....	.....	.....	.....
	Stone City....	Dolomite	.....	.....	.....	.....	.....	.....
	Stone City....	Dolomite	10.20	10.64	11.28	11.67	12.17	.....
	Stone City....	Dolomite.	8.94	9.38	9.84	10.20	10.69	.....
	Stone City....	Dolomite	7.62	8.28	8.72	9.10	9.54	.....
	Stone City....	Dolomite	10.06	10.55	11.07	11.50	12.00	.....
	Stone City....	Dolomite.........	8.73	9.08	9.66	9.98	10.40	.....
	Stone City....	Dolomite.........	9.30	9.72	10.22	10.62	11.10	.....
	Stone City....	Dolomite	9.49	9.84	10.42	10.92	11.37	.....
	Stone City....	Dolomite.........	9.32	9.83	10.32	10.83	11.28	.....
	Stone City....	Dolomite.........	9.20	9.58	10.15	10.67	10.93	.....
	Stone City....	Dolomite.........	6.02	6.38	6.81	7.34	7.55	.....
	Stone City....	Dolomite	6.62	6.92	7.30	7.90	8.08	.....
	Stone City....	Dolomite.........	7.58	7.95	8.46	8.88	9.32	.....
	Stone City....	Dolomite	7.72	8.19	8.64	9.23	9.59	.....
	Stone City....	Dolomite	7.72	8.36	8.82	9.61	9.73	.....
Madison . ..	Winterset....	Limestone..	.....	.....	.....	.....	.....	.....
Mahaska ...	Oskaloosa. ...	Limestone.	.....	.....	.....	.....	.....	.....
Marion	Tracy...... ..	Limestone.	.....	.....	.....	.....	.....	.....
	Red Rock. ...	Sandstone.........	.....	.....	.....	.....	.....	.....
	Red Rock. ...	Sandstone....... ..	.....	.....	.....	.....	.....	.....

No. IV.

INCREASE IN PERCENTAGE.

Number of Hours in Water							Authority	Remarks
168	264	336	432	510	700	Not known		
4.15	.....	.....	.....	.....	.....	.....	Murray..	Coal Measures
1.87	.....	.....	.....	.....	.....	.....	do	John Loftus quarry
0.74	.....	.....	.....	.....	.....	.....	do	John Loftus quarry
6.10	6.45	6.53	6.68	6.81	6.88	.....	C. E. Dept.	
6.47	6.76	6.88	7.06	7.16	7.32	.....	do	
7.18	7.44	7.56	7.77	7.89	8.08	.....	do	
6.33	6.64	6.72	6.92	7.05	7.22	.....	do	
6.24	6.57	6.66	6.82	6.95	7.15	.....	do	
4.31	.....	.....	.....	.....	.....	.....	Murray..	Mastin & Sterns
8.64	.....	.....	.....	.....	.....	.....	do	Kemper, Coal Measures
7.48	.....	.....	.....	.....	.....	.....	do	Champion quarry, spalls from crushing machine
9.37	.....	.....	.....	.....	.....	.....	do	Champion quarry
6.91	.....	.....	.....	.....	.....	.....	do	Champion quarry, dressed cube
.....	.....	.....	.....	.....	.....	5.45	G. S. Morrison	Champion quarry
13.07	13.62	13.94	14.23	14.50	14.81	.....	C. E. Dept.....	J. A. Green
11.56	12.08	12.38	12.61	12.81	13.02	.....	do	J. A. Green
10.39	10.92	11.21	11.46	11.62	11.93	.....	do	J. A. Green
12.86	13.21	13.57	13.88	14.03	14.33	.....	do	J. A. Green
11.24	11.57	11.90	12.21	12.41	12.75	.....	do	J. A. Green
11.93	12.47	12.71	13.06	13.30	13.52	.....	do	J. A. Green
12.30	12.88	13.12	13.47	13.71	14.03	.....	do	J. A. Green
12.10	12.83	13.08	13.36	13.66	14.00	.....	do	J. A. Green
11.63	12.34	12.52	12.80	13.04	13.41	.....	do	J. A. Green
7.98	8.40	8.50	8.72	8.88	9.14	.....	do	Dearborn & Sons
8.43	9.29	9.40	9.49	9.70	10.06	.....	do	Dearborn & Sons
9.69	10.57	10.73	10.93	11.11	11.44	.....	do	Dearborn & Sons
10.02	10.82	11.01	11.27	11.50	11.83	.....	do	Dearborn & Sons
10.22	10.92	11.12	11.32	11.56	11.84	.....	do	Dearborn & Sons
.....	.....	.....	.....	.....	.....	0.42	Rock Island Arsenal..	Bevington quarry
3.34	.....	.....	.....	.....	.....	.....	Murray.	St. Louis limestone
3.27	.....	.....	.....	.....	.....	.....	do	Steel, a broken piece
10.82	.....	.....	.....	.....	.....	.....	do	Dunreith, Coal Measures
10.82	.....	.....	.....	.....	.....	.....	do	Dunreith, Coal Measures

TABLE No. IV—

County	Location of Quarry	Kind of Stone	Number of Hours in Water					
			1	8	24	48	72	144
Marshall ..	Quarry.	Oölite.	0.85	.....	2.66	.....	.....	2.75
	Quarry.	Oölite.	1.56	.....	3.95	.....	.....	4.05
	Quarry.	Oölite........	1.20	.....	2.50	.....	.....	2.61
	Quarry.	Oölite..............	0.71	.....	2.11	.....	.....	2.20
	Quarry.	Oölite.....	1.50	.....	2.55	.....	.....	2.64
	Quarry.	Iowa marble	2.33	.....	3.60	.....	.....	3.87
	Quarry.	Iowa marble.	1.81	.....	3.31	.....	.....	3.57
	Quarry.	Iowa marble	2.31	.....	3.97	.....	.....	4.37
	Quarry........	Blue limestone.....	0.45	.....	1.86	.....	.....	2.02
	Quarry........	Limestone........	0.72	.....	1.72	.....	.....	1.79
	Quarry	Limestone	0.22	.....	0.70	.....	.....	0.77
	Quarry	Limestone.	0.06	.....	1.65	.....	.....	1.79
	Quarry	Limestone.	0.22	.....	1.64	.....	.....	1.79
	Quarry	Blue limestone.....	2.03	.....	3.17	.....	.....	3.36
	Quarry	Blue limestone.....	4.00	.....	5.41	.....	.....	5.65
Scott.......	LeClaire......	Limestone	.....	.....	.....	.....	.....	.....
	LeClaire......	Limestone	6.33	6.62	6.93	7.33	7.52	.....
	LeClaire......	Limestone	5.41	5.71	5.92	6.17	6.28	.....
	LeClaire......	Limestone	7.08	7.31	7.62	8.03	8.28	.....
	LeClaire......	Limestone	6.75	7.11	7.37	7.75	7.92	.....
	LeClaire......	Limestone	7.27	7.56	7.87	8.32	8.49	.....

STONE FROM COMPETING

Illinois	Joliet	Dolomite	.....	.....	.....	.....	.....	.....
	Lemont.......	Limestone	.....	.....	.....	.....	.....	.....
Indiana	Bedford	Oölite	.....	.....	.....	.....	.....	.....
	Bedford	Blue Oölite	3.47	3.66	3.79	4.01	4.08	.....
	Bedford	Blue Oölite	3.53	3.68	3.85	4.07	4.09	.....
	Bedford	Buff Oölite	4.57	4.76	4.95	5.19	5.23	.....
	Bedford	Buff Oölite	4.72	4.90	5.16	5.25	5.34	.....
Michigan ...	Lake Superior	Red Sandstone.....	5.91	6.24	6.47	6.92	7.06	.....
	Lake Superior	Red Sandstone.....	6.13	6.46	6.68	7.06	7.28	.....
	Lake Superior	Red Sandstone.....	4.79	4.94	5.26	5.67	5.70	.....
Minnesota ..	Kasota	Dolomite	.....	.....	.....	.....	.....	.....
	Winona	Dolomite	.....	.....	.....	.....	.....	.....
	Pipestone.....	Quartzite	.....	.....	.....	.....	.....	.....
Ohio	Berea.........	Sandstone	.....	.....	.....	.....	.....	.....
	Cleveland.....	Sandstone	5.06	5.40	5.70	5.83	6.07	.....

CONTINUED.

Number of Hours in Water							Authority	Remarks
168	264	336	432	510	700	Not Known		
.....	.....	.....	.....	.....	.....	.....	C. E. Dept. ...	Fine grained, northeast quarry
.....	.....	.....	.....	.....	.....	.....	do	Fine grained, northeast quarry
.....	.....	.....	.....	.....	.....	.....	do	Southeast quarry
.....	.....	.....	.....	.....	.....	.....	do	Southeast quarry
.....	.....	.....	.....	.....	.....	.....	do	Southeast quarry
.....	.....	.....	.....	.....	.....	.....	do	West quarry
.....	.....	.....	.....	.....	.....	.....	do	West quarry
.....	.....	.....	.....	.....	.....	.....	do	West quarry
.....	.....	.....	.....	.....	.....	.....	C. E. Dept.....	Northeast quarry
.....	.....	.....	.....	.....	.....	.....	do	Fossiliferous, N. E. quarry
.....	.....	.....	.....	.....	.....	.....	do	Fossiliferous, N. E. quarry
.....	.....	.....	.....	.....	.....	.....	do	Fossiliferous, west quarry
.....	.....	.....	.....	.....	.....	.....	do	Fossiliferous, west quarry
.....	.....	.....	.....	.....	.....	.....	do	Timber creek
.....	.....	.....	.....	.....	.....	.....	do	Timber creek
4.32	.....	.....	.....	.....	.....	.....	Murray	
7.84	8.29	8.43	8.69	8.83	8.98	.....	C. E. Dept.	
6.40	6.83	6.93	7.03	7.11	7.22	.....	do	
8.54	8.97	9.15	9.33	9.40	9.53	.....	do	
8.28	8.72	8.84	9.02	9.17	9.30	.....	do	
8.88	9.31	9.45	9.65	9.77	9.98	....	do	
LOCALITIES OUTSIDE OF IOWA.								
.....	.....	.....	.....	.....	.....	1.08	Gilmore	
.....	.....	.....	.....	.....	.....	1.12	Gilmore	
.....	.....	.....	.....	.....	.....	4.34	Hopkins	
4.12	4.44	4.51	4.57	4.62	4.77	.....	C. E. Dept.	
4.25	4.56	4.64	4.75	4.80	4.95	.....	do	
5.51	5.81	5.88	6.03	6.07	6.24	.....	do	
5.78	5.95	6.11	6.23	6.28	6.53	.....	do	
7.55	8.13	8.30	8.53	8.66	8.89	.....	do	
7.93	8.39	8.56	8.80	8.86	9.16	.....	do	
6.43	6.85	6.99	7.17	7.31	7.63	.....	do	
.....	.....	.....	.....	.....	.....	3.57	Winchell	
.....	.....	.....	.....	.....	.....	4.76	Winchell	
.....	.....	.....	.....	.....	.....	.....	Gilmore	
.....	.....	.....	.....	.....	.....	4.76	Gilmore	
6.89	7.08	7.52	7.63	7.79	8.01	.....	C. E. Dept.	

TABLE No. V.

FREEZING TESTS.*

SAMPLES TAKEN FROM THE QUARRIES OF THE LE GRAND QUARRY CO.

Kind of Stone	Height of cube	Surface dimensions	Area	Breaking Load in Lbs.		Load Per Square Inch		Loss in weight in per cent	Remarks
				Spalling began	Failure	Spalling began	Failure		
Oölite, fine-grained, northeast quarry	2.05	2.00x2.08	4.16	55,700	56,400	13,390	13,558	0.0014	Loud report
do	2.08	2.00x2.08	4.16	26,000	......	6,250	14,280	0.0013	Sustained 59,400 lbs. Very slight spall at 26,000 lbs
Oölite, fine-grained, southeast quarry	1.99	1.97x2.00	3.94	50,000	60,000	12,690	15,230	......	Loud report and cube much shattered
do	2.00	2.00x1.96	3.92	34,000	55,700	8,673	14,210	......	do
do	2.02	1.97x1.97	3.88	50,000	56,500	12,890	14,560	......	do
Iowa marble, west quarry	1.96	2.02x2.02	4.08	50,000	56,500	12,255	13,850	0.0007	Broke with a loud report
do	1.92	2.00x2.00	4.00	42,600	52,700	10,650	13,175	0.0008	do
do	2.00	2.04x2.02	4.12	38,000	51,700	9,225	12,550	0.0009	do
Blue limestone, northeast quarry	2.00	1.98x1.97	3.90	......	......	......	15,360†	......	59,400 lbs. applied without effect
Fossiliferous limestone, N. E. quarry	2.00	2.00x2.02	4.08	......	......	......	14,560†	......	59,400 lbs. applied without effect
do	1.98	1.97x2.00	3.94	55,600	......	14,035	14,900†	......	59,400 lbs. sustained
Fossiliferous limestone, west quarry	1.98	2.04x2.02	4.12	35,900	40,000	8,715	9,710	......	Weak report
do	1.97	1.99x1.96	3.91	30,500	35,000	7,800	8,950	......	Weak report
Blue limestone, Timber creek	2.00	2.04x2.01	4.10	28,000	36,300	6,830	8,850	......	Slight report‡
do	1.96	1.98x1.96	3.88	32,700	32,700	......	8,430		

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*The cubes were placed in distilled water until completely saturated, after which the specimens were encased in cotton batting saturated with distilled water and placed in wooden trays, eight by eight inches and two inches deep, provided with wire bottoms. The trays after being securely packed were placed in the refrigerator and kept at a temperature of from 17° to 19° F. for forty-eight hours. Then they were removed from the refrigerator and subjected to a temperature of 70° F. for twenty-four hours. This process was repeated six times. The specimens were afterwards subjected to refrigeration and thawing ten times; but the conditions were less constant than in the first six. In the latter series the minimum temperatures ranged from 21° to 32° F.

†The above table shows that the blocks suffered no appreciable loss in weight or strength during the investigation. It is highly probable that lower temperatures would have given very different results.

‡In spite of the apparent weakness, low specific gravity and rather high percentage of absorption, the quarry face along natural fissures shows this stone to be one of the most durable quarried in the county.

TABLE No. VI.

FREEZING AND THAWING TESTS.

Number of specimen	Dry weight	Saturated weight	Number of Freezings		Remarks
			10	20	
1	39.80	42.54	42.45	42.39	Wilkes Williams quarry
2	39.09	41.95	41.84	41.81	Wilkes Williams quarry
3	42.47	45.90	45.76	45.79	Wilkes Williams quarry
4	44.12	47.30	47.15	47.13	Wilkes Williams quarry
5	45.06	48.28	48.02	47.96	Wilkes Williams quarry
6	31.53	36.20	35.69	35.74	J. A. Green quarry
7	34.35	38.82	38.24	38.23	J. A. Green quarry
8	31.76	35.55	35.05	35.11	J. A. Green quarry
9	32.49	37.15	36.74	36.71	J. A. Green quarry
10	34.35	38.60	38.20	38.05	J. A. Green quarry
11	33.85	38.43	37.83	37.71	J. A. Green quarry
12	34.14	38.93	38.33	38.26	J. A. Green quarry
13	33.51	38.20	37.48	37.70	J. A. Green quarry
14	32.81	37.21	36.63	36.82	J. A. Green quarry
15	41.98	45.82	45.39	45.37	Dearborn & Sons quarry
16	39.59	43.57	42.85	42.87	Dearborn & Sons quarry
17	35.11	39.13	38.44	38.57	Dearborn & Sons quarry
18	35.77	40.00	39.37	39.33	Dearborn & Sons quarry
19	34.45	38.53	37.90	37.74	Dearborn & Sons quarry
20	35.23	38.39	38.27	38.38	LeClaire Stone Company
21	39.22	42.05	42.04	42.18	LeClaire Stone Company
22	39.24	42.98	42.67	43.14	LeClaire Stone Company
23	39.26	42.91	42.75	42.58	LeClaire Stone Company
24	35.34	38.87	38.82	38.53	LeClaire Stone Company
25	46.13	48.33	48.05	48.03	Stone obtained from Fred Andrews
26	45.64	47.90	47.51	47.56	Stone obtained from Fred Andrews
27	46.45	49.35	49.02	49.03	Stone obtained from Fred Andrews
28	30.61	33.33	33.00	33.05	Stone obtained from Fred Andrews
29	36.70	40.06	39.60	39.74	Stone obtained from Fred Andrews
30	40.90	43.97	43.32	43.40	Stone obtained from Fred Andrews
31	43.02	45.40	45.15	44.37	Stone obtained from Fred Andrews
32	36.69	39.63	39.01	39.38	Stone obtained from Fred Andrews

DIRECTORY OF IOWA

Limestone and Sandstone

QUARRIES

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
ALLAMAKEE COUNTY.					
John M. Hartong....	Church	Oneota..........	Dolomite...........	Hand work..........	Building and rubble
D. Keffeler	Church	Oneota..........	Dolomite...........	Hand work	Building and rubble
William P. Truax ...	Harpers Ferry....	Oneota..........	Dolomite...........	Hand work..........	Building and rubble
William B. Miller....	Lansing..........	Oneota..........	Dolomite...........	Hand work	Rubble
Reppe Bros..........	Lansing..........	Oneota	Dolomite...........	Hand work..........	Building and flagging
APPANOOSE COUNTY.					
William B. Swan....	Plano	Des Moines......	....	Hand work	Building and curbing
BENTON COUNTY.					
Eck Lahne..........	Garrison	Cedar Valley	Hard, fine-grained, white limestone...	Hand work..........	Rubble
J. W. Thompkin.....	Garrison	Cedar Valley	Hard, fine-grained, white limestone...	Hand work	Rubble
Mrs. Margaret Wenner	Garrison	Cedar Valley	Hard, fine-grained, white limestone...	Hand work..........	Rubble
M. G. Combes.......	Shellsburg	Cedar Valley	Gray limestone.	Hand work	Building and rubble
James Rife.....	Shellsburg	Cedar Valley	....	Hand work..........	Building and rubble
John Trinder........	Vinton	Wapsipinicon....	....	Hand work..........	Building and rubble
Herman W. Kearns..	Vinton	Wapsipinicon....	Yellow, fine-grained, hard, magnesian limestone.........	Hand work....	Building and rubble
Mrs. R. H. Quinn....	Vinton	Wapsipinicon....	Gray, buff, brecciated limestone......	....	Building and rubble
Ephraim Rosenburg..	Vinton	Wapsipinicon....	Gray, buff, brecciated limestone......	....	Building and riprap

BLACK HAWK COUNTY.

Owen Drumm	Cedar Falls	Cedar Valley	Varying from pure to highly magnesian limestone	Hand work	Building and riprap
Houghtaling & Gillan	Cedar Falls	Cedar Valley	Varying from pure to highly magnesian limestone	Hand work	Rubble
Jens Nielsen	Cedar Falls	Cedar Valley	Varying from pure to highly magnesian limestone	Hand work	Building, dressed flagging
E. M. Cuddebeck	Cedar Falls	Cedar Valley	Varying from pure to highly magnesian limestone	Hand work	
E. J. Buchan	Laporte	Cedar Valley	Varying from pure to highly magnesian limestone	Hand work	Building, rubble and crushed stone
James F. Camp	Laporte	Cedar Valley	Varying from pure to highly magnesian limestone	Hand work	Macadam and rubble
C. R. Harmon	Laporte	Cedar Valley	Varying from pure to highly magnesian limestone	Hand work	Building and rubble
A. K. Longaker	Laporte	Cedar Valley	Varying from pure to highly magnesian limestone	Hand work	Building
John Mersch	Laporte	Cedar Valley	Varying from pure to highly magnesian limestone	Hand work	Building and rubble
John M. Trip	Laporte	Cedar Valley	Varying from pure to highly magne sian limestone	Hand work	Building and rubble
Bartlett & McFarlane	Waterloo	Cedar Valley	Varying from pure to highly magnesian limestone	Hand work	Building and rubble

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
			BREMER COUNTY.		
Cedar River Stone Co.	Waverly..........	Cedar Valley	Magnesian limestone	Crusher plant, steam drills....	Rubble and crushed stone
			BUCHANAN COUNTY.		
A. B. Kiefer.........	Coytown.........	Hopkinton.......	Gray and blue, fine-grained, non-dolomitized limestone	Hand work....	Building, rubble, flagging, curbing, etc.
			CEDAR COUNTY.		
Cedar Valley Stone Co.....	Cedar Valley.....	Anamosa..	Evenly bedded, vesicular dolomite...	Channelers, steam drills, crusher plant, dressing plant......	Building.. { rough, dressed, bridge, rubble, riprap, crushed stone, etc.
			CERRO GORDO COUNTY.		
The Barber Asphalt Paving Co.........	Mason City.......	Cedar Valley	White limestone and sugary dolomite...	Crusher plant........	Crushed stone
H. Kuppinger & Bros.	Mason City.......	Cedar Valley	White limestone and sugary dolomite...	Hand work......	Building and rubble

Mason City Lime & Cement Co	Mason City	Cedar Valley	White limestone and sugary dolomite	One kiln	Lime
Mason City Quarry Co	Mason City	Cedar Valley	White limestone and sugary dolomite	Hand work	Building, rubble, riprap, flagging
Northwestern States Portland Cement Co	Mason City	Cedar Valley	White limestone and sugary dolomite	Crusher plant, complete Portland cement plant with up-to-date equipment in process of building	Rubble and crushed stone at present
C. K. Quinby	Mason City	Cedar Valley	White limestone and sugary dolomite	Hand work	Building, rubble, flagging
CHICKASAW COUNTY.					
L. L. Layton	Nashua	Cedar Valley	Thin bedded, magnesian limestone	Hand work	Rubble, macadam
CLARKE COUNTY.					
Wm. & M. H. Busick	Osceola	Missouri	White limestone	Hand work	Building, flagging, curbing
J. N. DeLong	Osceola	Missouri	White limestone	Hand work	Building, flagging, curbing and macadam
O. O. Fenn	Osceola	Missouri	White limestone	Hand work	Building and rubble
J. O. Girthoffer	Osceola	Missouri	White limestone	Hand work	
S. A. Johnson	Osceola	Missouri	White limestone	Hand work	Building, flagging, rubble
Wm. H. Petrie	Osceola	Missouri	White limestone	Hand work	Building, rubble
W. M. Short	Osceola	Missouri	White limestone	Hand work	Building, flagging

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES—CONTINUED.

CLAYTON COUNTY.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
Charles Lee	Elkader	Platteville	Thin bedded limestone	Hand work	Rubble, lime
James G. Cassidy	Elkader	Platteville		Hand work	Building, lime, flagging, curbing, crushed stone
Curtis H. Williamson	Elkader			Hand work	
E. W. & H. D. Kregel	Garnavillo	Galena		Hand work	Rubble, flagging, paving
George Kohler	Guttenberg	Platteville	Gray, fine-grained limestone, some magnesian	One kiln	Lime
Franz Stoeffler, Sr.	Guttenberg	Platteville	Gray, fine-grained limestone, some magnesian	One kiln	Building, lime
Joseph Vogt	Guttenberg	Platteville	Gray, fine-grained limestone, some magnesian	One kiln	Lime, rubble
Frank T. Boyle	McGregor	Platteville	Blue, fine-grained limestone	Hand work	Building, curbing, paving
John Shadle	Volga	Galena		Hand work	Building, paving

CLINTON COUNTY.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
Nelis Kaarde	Lyons				
Geo. H. & Herbert Mowry	Big Rock	Hopkinton	Brown to bluish gray magnesian limestone	Hand work	

August Kuehl	Big Rock	Hopkinton	Brown to bluish gray magnesian limestone	Hand work	Rubble, riprap
Claus F. Lorenzen	Big Rock	Hopkinton	Brown to bluish gray magnesian limestone	Hand work	Building, macadam, riprap
Mrs. Louise Moeller	Big Rock	Hopkinton	Brown to bluish gray magnesian limestone	Hand work	Rubble
S. B. Walker	Calamus	Hopkinton	Brown to bluish gray magnesian limestone	Hand work	
Thomas Carey & Son	Clinton	Hopkinton	Brown to bluish gray magnesian limestone	Portable jaw crusher	Building, rubble, crushed stone
Thomas Purcell	Clinton	Hopkinton	Brown to bluish gray magnesian limestone	Hand work	Rubble
Albert A. Barber	Grand Mound	Hopkinton	Brown to bluish gray magnesian limestone	Hand work	Rubble
John H. Frederick	Grand Mound	Hopkinton	Brown to bluish gray magnesian limestone	Hand work	
Anton H. Green	Grand Mound	Hopkinton	Brown to bluish gray magnesian limestone	Hand work	Building, rubble
J. O. Miller	Grand Mound	Hopkinton	Brown to bluish gray magnesian limestone	Hand work	
		DAVIS COUNTY.			
Jeff Carter	Eldon	St. Louis		Hand work	

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
			DECATUR COUNTY.		
Davis City Stone Crusher Co.	Davis City	Missouri	White limestone	Crusher plant	Building, rubble, crushed stone
J. W. Valentine	Davis City	Missouri	White limestone	Hand work	Rubble
W. E. Lee	Davis City	Missouri	White limestone	Hand work	Building, rubble, crushed stone
John Lovell	Davis City	Missouri	White limestone	Hand work	Building, curbing
J. W. West	De Kalb	Missouri	White limestone	Hand work	Building, riprap
W. H. Campbell	Grand River	Missouri	White limestone	Hand work	
			DELAWARE COUNTY.		
Fred A. Bort	Hopkinton	Hopkinton	Even bedded, fine-grained dolomite	Hand work	Building, rubble
E. M. Loop	Hopkinton	Hopkinton	Gray to buff dolomite	Hand work	Building, lime, riprap
M. L. McGlade	Hopkinton	Hopkinton	Gray to buff dolomite	Hand work	Building, flagging, curbing, crushed stone, etc.
James Milroy	Hopkinton	Hopkinton	Gray to buff dolomite	Hand work	Rubble
F. E. Williamson	Hopkinton	Hopkinton	Gray to buff dolomite	Hand work	Rubble

DES MOINES COUNTY.

Burlington City Quarry	Burlington	Osage	White, buff, yellow limestone	Hand work	Building, rubble, crushed stone
E. G. Kemper	Burlington	Osage	White, buff, yellow limestone	Crusher plant	Rubble, crushed stone
Geo. Koeslner	Burlington	Osage	White, buff, yellow limestone	Hand work	
Albert Mirchner	Burlington	Osage	White, buff, yellow limestone	Hand work	Riprap
John J. Loftus	Burlington	Osage	White, buff, yellow limestone	Hand work	Building, rubble, riprap
Henry Magle	Burlington	Osage	White, buff, yellow limestone	Hand work	Building, rubble
Matthias Miller	Burlington	Osage	White, buff, yellow limestone	Hand work	Building, rubble
Horace Patterson	Burlington	Osage	White, buff, yellow limestone	Hand work	Building, rubble
Perry W. Whitaker	Burlington	Osage	White, buff, yellow limestone	Hand work	Dimension, rubble, flagging, curbing and crushed stone
C. F. Nagel	Picnic Point	Osage	White, buff, yellow limestone	Hand work	
P. R. Hartzell	West Burlington	Osage	White, buff, yellow limestone	Hand work	Building, rubble, riprap

DUBUQUE COUNTY.

H. L. Dehner	Cascade	Hopkinton	Evenly bedded dolomite	Hand work	Building, rubble, crushed stone
M. E. Parker	Cascade	Hopkinton	Evenly bedded dolomite	Hand work	Rubble, crushed stone
John Becker	Dubuque	Galena	Granular, hard dolomite	Hand work	Rubble
Byrne & Saul	Dubuque	Galena	Granular, hard dolomite	Hand work	Building, rubble, crushed stone, riprap

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
		DUBUQUE COUNTY—CONTINUED.			
Thomas Byrne	Dubuque	Galena	Granular, hard dolomite	Hand work	
T. J. Donahue	Dubuque	Galena	Granular, hard dolomite	Hand work	Building, rubble
Eagle Point Lime Works	Dubuque	Galena	Granular, hard dolomite	Crusher plant, lime kilns	Lime, crushed stone
Peter Eisbech	Dubuque	Galena	Granular, hard dolomite	Hand work	Building, rubble
Gerhard Mersch	Dubuque	Galena	Granular, hard dolomite	Hand work	Rubble, curbing, paving
Anthony Siege	Dubuque	Galena	Granular, hard dolomite	Hand work	Building, rubble, curbing, crushed stone
James Street	Dubuque	Galena	Granular, hard dolomite	Hand work	Building, rubble
Chas. Brodfield	Epworth	Hopkinton	Dolomite	Hand work	Building, rubble
Fred E. Sefzik	Epworth	Hopkinton	Dolomite	Hand work	Building, rubble
B. N. Arquitt & Sons	Farley	Hopkinton	Dolomite	Hand work	Dimension, rubble, crushed stone
Tibey Bros	Julian	Galena	Dolomite	Hand work	
Frank Heitzman	Sherrill	Galena	Dolomite	Lime kiln	Lime
		FAYETTE COUNTY.			
J. M. Hicks	Arlington	Hopkinton	Coarse, yellow dolomite	Hand work	Building, rubble
Lew Rittenhouse	Arlington	Hopkinton	Coarse, yellow dolomite	Hand work	
Bartlett & Bartlett	Brainard	Hopkinton	Coarse, yellow dolomite	Hand work	

J. L. Ishman	Douglass	Hopkinton	Coarse, yellow dolomite	Kiln	Lime
R. W. Helmes	Brainard	Hopkinton	Coarse, yellow dolomite	Hand work	Building, rubble
Christian Lortscher	Elgin	Hopkinton	Coarse, yellow dolomite	Hand work	Building, rubble, riprap
T. J. Miller	Elgin	Hopkinton	Coarse, yellow dolomite	Hand work	
J. J. Coonrod	Oelwein	Hopkinton	Coarse, yellow dolomite	Hand work	
Wilkes Williams	Postville	Hopkinton	Massive dolomite	Steam drills and derricks	Dimension stone, rubble
Dorland & Weed	West Union	Devonian	Yellow, earthy magnesian limestone	Hand work	Rubble

FLOYD COUNTY.

Bunn Bros	Charles City	Cedar Valley	White limestone and dolomitic limestone	Hand work	Building, rubble
Ed. Gayther, Jr	Charles City	Cedar Valley	White limestone and dolomitic limestone	Hand work	Rubble
Geo. W. Kuhnle	Charles City	Cedar Valley	White limestone and dolomitic limestone	Hand work	Rubble
Chas. H. Morrison	Charles City	Cedar Valley	White limestone and dolomitic limestone	Hand work	Rubble, building
S. H. Waddell	Charles City	Cedar Valley	White limestone and dolomitic limestone	Hand work	Building, rubble
N. Rosenkrans	Marble Rock	Cedar Valley	White limestone, very evenly bedded below	Hand work	Building, rubble

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
FLOYD COUNTY—CONTINUED					
Haynes Bros.........	Marble Rock.....	Cedar Valley	White limestone, very evenly bedded below........	Hand work	Building, rubble, flagging
Chas. D. Smith......	Marble Rock.....	Cedar Valley	White limestone, very evenly bedded below........	Hand work......	Building, rubble
McElroy & Hodge....	Rockford.........	Cedar Valley	White limestone, very evenly bedded below........	Hand work....	Building, rubble
GRUNDY COUNTY.					
W. A. Conrad.........	Conrad...........	Kinderhook......	Oölite..............	Hand work	Rubble
HAMILTON COUNTY.					
C. A. Swanson	Webster City.....	St. Louis	Earthy limestone....	Hand work......	Rubble
HARDIN COUNTY.					
N. J. Wheeler	Alden............	Kinderhook......	White limestone, compact..........	Hand work....	Building, flagging

W. A. Baldcn........	Alden...........	Kinderhook......	White limestone, compact....... ...	....	Building, flagging
Barber Asphalt Paving Co............	Iowa Falls........	Kinderhook......	Hard, white limestone and sugary dolomite..........	Crusher plant........	Crushed stone
W. H. Baskerville...	Iowa Falls........	Kinderhook......	Hard, white limestone and sugary dolomite..........	Hand work....	Rubble
V. A. Biggs..........	Iowa Falls........	Kinderhook......	Hard, white limestone and sugary dolomite..........	Hand work...........	Building, rubble
Ellsworth Stone Co..	Iowa Falls........	Kinderhook......	Hard, white limestone and sugary dolomite........ ...	Crusher plant........	Dimension, rubble, crushed stone
W. E. Taylor........	Iowa Falls........	Kinderhook......	Hard, white limestone and sugary dolomite..........	Hand work....	Rubble

HENRY COUNTY.

Beckwith Stone & Lime Co...........	Mt. Pleasant......	St. Louis	Hard, compact limestone to magnesian limestone......	Portable jaw crusher..	Rubble, crushed stone
R. Brown & Co......	Mt. Pleasant......	St. Louis	Hard, compact limestone to magnesian limestone	Hand work	
Daniel Cronin.......	Mt. Pleasant......	St. Louis	Hard, compact limestone to magnesian limestone	Hand work....	Rubble
James Purdie........	Mt. Pleasant......	St. Louis	Hard, compact limestone to magnesian limestone	Hand work.........	Rubble
Ed. M. Masden......	Salem..	St. Louis	Hard, compact limestone to magnesian limestone	Hand work	Rubble

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
HOWARD COUNTY.					
Cresco City Quarry..	Cresco..........	Wapsipinicon....	Magnesian, argillaceous limestone...	Hand work..........	Macadam
John Hallman.......	Cresco..........	Wapsipinicon....	Magnesian, argillaceous limestone...	Hand work....	Building, rubble
John Croft...........	Elma............	Cedar Valley.....	Coarse dolomite	Hand work....	Rubble
E. E. Evans.........	Elma.	Cedar Valley.....	Coarse dolomite	Hand work	Building, crushed stone
Wm. H. Patterson...	Vernon Springs...	Cedar Valley.....	Soft dolomitic limestone above, blue limestone below...	Hand work....	Rubble, macadam
HUMBOLDT COUNTY.					
M. L. Peckham & Son	Humboldt........	Kinderhook......	White limestone and oölite............	Hand work..	Rubble, macadam
JACKSON COUNTY.					
Fred W. Ernest, Sr..	Bellevue	Maquoketa.......	Yellow, impure limestone..........	Hand work....	Building, rubble
C. G. Hyler.........	Bellevue	Maquoketa and Hopkinton.....	Impure limestone, yellow dolomite...	Hand work....	Lime
John Keil...........	Bellevue	Maquoketa.......	Yellow, impure limestone.......	Hand work	Building, macadam
Frank Sommers	Bellevue	Maquoketa.......	....	Hand work	
Levi Beavers........	Maquoketa.......	Hopkinton.......	Massive dolomite....	Hand work	

Alfred Hurst & Co.	Maquoketa	Hopkinton	Massive dolomite	Lime kilns, steam drills	Lime, macadam
O. W. Joiner & Son.	Maquoketa	Hopkinton	Massive dolomite	Lime kilns	Building, lime, macadam
Wm. Martin	Maquoketa	Hopkinton	Massive dolomite	Hand work	
W. D. Palmer	Maquoketa	Hopkinton	Massive dolomite	Hand work	
James Roe	Maquoketa	Hopkinton	Massive dolomite		
L. B. Stuart & Co.	Monmouth	Hopkinton	Massive dolomite	Kilns	Lime
		JOHNSON COUNTY.			
Ed. L. Crowley	Iowa City	Cedar Valley		Hand work	Building and rubble
E. P. Hutchinson	Iowa City	Cedar Valley	Blue and gray limestone	Hand work	Building, macadam
		JONES COUNTY.			
James Lawrence	Anamosa	Anamosa	Evenly bedded, vesicular dolomite	Hand work	Building, rubble
Penitentiary Quarry	Anamosa	Anamosa	Evenly bedded, vesicular dolomite	Steam drills and derricks	Dimension { rough, dressed, flagging, rubble, curbing, riprap
O. J. Austin	Hale	Anamosa	Evenly bedded, vesicular dolomite	Hand work	Building rubble
Jno. Christopherson	Hale	Anamosa	Evenly bedded, vesicular dolomite	Hand work	Building, rubble
Geo. Osborne	Hale	Anamosa	Evenly bedded, vesicular dolomite	Hand work	Building, rubble
C. O. Woodard	Hale	Anamosa	Evenly bedded, vesicular dolomite	Hand work	Rubble, flagging
August Hartwig	Olin	Anamosa	Evenly bedded, vesicular dolomite	Hand work	

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
			JONES COUNTY—CONTINUED		
Lewis Story	Olin	Anamosa	Evenly bedded, vesicular dolomite	Hand work	
H. Dearborn & Sons	Stone City	Anamosa	Evenly bedded, vesicular dolomite	Steam channeler, drills, derricks and crusher plant	Dimension { rough, dressed, bridge, rubble, riprap, crushed stone, etc.
F. Erickson & Co.	Stone City	Anamosa	Evenly bedded, vesicular dolomite	Steam channeler, drills, derricks and crusher plant	Dimension { rough, dressed, bridge, rubble, riprap, crushed stone, etc.
J. A. Green & Sons	Stone City	Anamosa	Evenly bedded, vesicular dolomite	Steam channeler, drills, derricks and crusher plant	Dimension { rough, dressed, bridge, rubble, riprap, crushed stone, etc.
John Ronen	Stone City	Anamosa	Evenly bedded, vesicular dolomite	Steam channeler, drills, derricks and crusher plant	Dimension { rough, dressed, bridge, rubble, riprap, crushed stone, etc.
			KEOKUK COUNTY.		
John Bitner	Delta	St. Louis	Compact earthy limestone	Hand work	
Phelps & Boland	Delta	St. Louis	Compact earthy limestone	Hand work	

John W. Anderson...	Hedrick..........	St. Louis	Pure to magnesian limestones, variable	Hand work...........	Rubble
B. F. Berry..........	Hedrick..........	St. Louis	Pure to magnesian limestones, variable	Hand work	
Chas. G. Sandusky..	Hedrick..........	St. Louis	Pure to magnesian limestones, variable	Hand work..	Building, rubble
W. H. Stevens......	Hedrick..........	St. Louis	Pure to magnesian limestones, variable	Hand work	
Geo. W. Watts.......	Hedrick..........	St. Louis	Pure to magnesian limestones, variable	Hand work	
A. A. Williams......	Hedrick..........	St. Louis	Pure to magnesian limestones, variable	Hand work......	Building, rubble
Joseph Ingle.........	Ollie	St. Louis	Pure to magnesian limestones, variable	Hand work	Building, rubble, flagging
I. M. Walker........	Richland.........	St. Louis	Pure to magnesian limestones, variable	Hand work....	Building, rubble, riprap
Chas. H. Miller......	Sigourney........	St. Louis	Pure to magnesian limestones, variable	Hand work....	Building, rubble
Frank Manion.......	Sigourney........	St. Louis	Pure to magnesian limestones, variable	Hand work	Building, rubble
LEE COUNTY.					
McManus & Tucker..	Ballinger Station.	Osage	Sub-crystalline, grayish blue limestone	Crusher plant, steam drills and derricks..	Building, rubble, riprap, crushed stone
Cameron & McManus	Keokuk..........	Osage	Sub-crystalline, grayish blue limestone	Crusher plant, steam drills and derricks..	Building, rubble, crushed stone
A. L. Carroll........	Keokuk	Osage	Sub-crystalline, grayish blue limestone	Hand work	
Harrison & Dietz	Keokuk	Osage	Sub-crystalline, grayish blue limestone	Hand work......	Building, rubble, riprap
Peter Kelly..........	Keokuk	Osage	Sub-crystalline, grayish blue limestone	Hand work	
W. H. Graham......	Montrose and Gallands	Osage	Sub-crystalline, grayish blue limestone	Hand work	

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
		LEE COUNTY—CONTINUED			
Kennedy & Wardlow.	Montrose.........	Osage	Sub-crystalline, grayish blue limestone	Hand work	
August Beach.......	West Point.......	St. Louis	Blue and brown limestone	Hand work....	Building, flagging, riprap
Geo. E. Craig.......	West Point.......	St. Louis	Blue and brown limestone	Hand work	
H. J. Neuweg........	West Point.......	St. Louis	Blue and brown limestone	Hand work......	Building, rubble
Chas. Graner, Sr....	Franklin	Kinderhook			
Henry Graner........	Franklin	Kinderhook			
Fred Hammer.......	Franklin	Kinderhook			
Henry Judy.........	Franklin	Kinderhook			
F. L. Pardall........	Franklin	Kinderhook			
Henry Sprenger......	Franklin	Kinderhook			
		LINN COUNTY.			
Bess Lime Works....	Cedar Rapids	Wapsipinicon....	Magnesian limestone	Kilns	
J. J. Snouffer, Jr....	Cedar Rapids	Wapsipinicon....	Magnesian limestone	Crusher plant........	Crushed stone
Wesley Lorence......	Mount Vernon....	Anamosa	Dolomite	Hand work	
E. L. Keith	Mount Vernon....	Anamosa	Dolomite	Hand work......	Building, rubble, crushed stone
Mt. Vernon Stone Co.	Mount Vernon....	Anamosa	Dolomite	Steam drills and derricks...............	Building, rubble
Jos. Pisny...........	Mount Vernon....	Anamosa	Dolomite	Hand work	
Joseph Hoolik........	Palisades.........	Anamosa	Dolomite	Hand work..	Building, rubble

Michael C. Walker...	Prairiesburg......	Anamosa........	Dolomite	Hand work	
Viola Lime Works...	Viola............	LeClaire.........	Massive dolomite....	Kilns................	Lime, rubble
Wm. M. Pickering...	Viola............	Gower...........	Massive dolomite....	Hand work	
LOUISA COUNTY.					
Mrs. Churchman	Cairo	Osage...........	Gray, sub-crystalline, pure limestone	Hand work	
J. M. Marshall.......	Columbus City...	Osage...........	Gray, sub-crystalline, pure limestone	Hand work..	Building, macadam, riprap
J. E. Gray...........	Columbus Jct	Osage...........	Gray, sub-crystalline, pure limestone	Hand work........ ...	Building, rubble
Jno. A. Hall.........	Columbus Jct	Osage...........	Gray, sub-crystalline, pure limestone	Hand work..	Building, rubble
J. Hayes Jones......	Columbus Jct	Osage...........	Gray, sub-crystalline, pure limestone	Hand work	
W. C. Bryant........	Morning Sun.....	Osage...........	Gray, sub-crystalline, pure limestone	Hand work	
W. A. Steele.........	Morning Sun.....	Osage...........	Gray, sub-crystalline, pure limestone	Hand work	
Chas. B. Wilson.....	Morning Sun.....	Osage...........	Gray, sub-crystalline, pure limestone	Hand work....	Building, rubble
John Ackenbom.....	Newport..........	Osage...........	Gray, sub-crystalline, pure limestone	Hand work...	Building, rubble
MADISON COUNTY.					
Earlham Land Co....	Earlham	Missouri	White to buff, compact limestones....	Steam derricks, drills and crusher plant ..	Dimension, rubble, crushed stone
S. A. Robertson.....	Earlham	Missouri	White to buff, compact limestones....	Steam derricks, drills and crusher plant ..	Dimension, rubble, crushed stone
Henry Taylor........	Earlham	Missouri	White to buff, compact limestones....	Hand work..	Building, rubble
Barnett Wilson......	Earlham	Missouri	White to buff, compact limestones....	Hand work....	Rubble

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
MADISON COUNTY—CONTINUED					
Joel Barnett	Earlham	Missouri	White to buff, compact limestones	Hand work	
Charles V. Brown	Earlham	Missouri	White to buff, compact limestones	Hand work	
Mile E. Brown	Earlham	Missouri	White to buff, compact limestones	Hand work	
F. V. Yoke	East Peru	Missouri	White to buff, compact limestones	Hand work	Rubble, crushed stone
Benton, Applegate & Son	Winterset	Missouri	White to buff, compact limestones	Hand work	Building, rubble
W. A. Hartman	Winterset	Missouri	White to buff, compact limestones	Hand work	Riprap, rubble
H. H. Edwards	Winterset	Missouri	White to buff, compact limestones	Hand work	
W. W. Cassidy & Co.	Winterset	Missouri	White to buff, compact limestones	Hand work	Building, rubble, crushed stone
MAHASKA COUNTY.					
T. B. Reese	Given	St. Louis	White to earthy limestone	Hand work	Building, rubble, flagging
Geo. N. Russell	Oskaloosa	St. Louis	White to earthy limestone	Hand work	

MARION COUNTY.					
John J. Loftus	Tracy	St. Louis	Compact, white limestone	Steam derricks, steam drills	Building, rubble, macadam, riprap
Hartsham & Garden	Tracy	St. Louis	Compact, white limestone	Hand work	Building, rubble, riprap
MARSHALL COUNTY.					
LeGrand Quarry Co.	Quarry	Kinderhook	Oölite, magnesian limestone, subcrystalline limestone	Steam derricks and crusher plant and air drills	Dimension { rough, dressed, rubble, riprap, crushed stone
MITCHELL COUNTY.					
L. P. Hendrickson	Orchard	Cedar Valley	White, compact limestones to brown dolomites	Hand work	Building, rubble
Sims Bros	Orchard	Cedar Valley	White, compact limestones to brown dolomites	Hand work	
Brenner & Rice	Osage	Cedar Valley	White, compact limestones to brown dolomites	Hand work	
Leander D. Green	Osage	Cedar Valley	White, compact limestones to brown dolomites	Hand work	
W. J. Wagner	Osage	Cedar Valley	White, compact limestones to brown dolomites	Hand work	
Baldwin Bros	Osage	Cedar Valley	White, compact limestones to brown dolomites	Hand work	

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
MONTGOMERY COUNTY.					
J. N. Fate	Elliott	Missouri	White, compact to earthy limestones.	Hand work	
Jas. Devine	Stennett	Missouri	White, compact to earthy limestones.	Hand work	
O. F. Remmers	Stennett	Missouri	White, compact to earthy limestones.	Hand work	
H. P. Light	Stennett	Missouri	White, compact to earthy limestones.	Hand work	Building, rubble
Jno. C. Perry	Stennett	Missouri	White, compact to earthy limestones.	Hand work	
H. L. Stennett	Stennett	Missouri	White, compact to earthy limestones.	Hand work	Building, rubble
POCAHONTAS COUNTY.					
Johnson & Freeberg	Gilmore City			Hand work	Rubble
A. N. Bull	Gilmore City	St. Louis	Compact, white limestone	Hand work	
Bull & Edgington	Gilmore City	St. Louis	Compact, white limestone	Hand work	
POTTAWATTAMIE COUNTY.					
John S. Woodburn	Macedonia	Missouri	Blue limestone	Hand work	

SCOTT COUNTY.

Geo. W. Randall	Big Rock				Building, rubble
Linwood Quarries Co.	Buffalo	Wapsipinicon	Argillaceous limestone	Steam drills, derricks and crusher plant	Crushed stone, riprap
Frank Boland	Bettendorf	Wapsipinicon		Hand work	Building, crushed stone
Gromoll Stone Co.	Bettendorf	Wapsipinicon		Steam drills, derricks and crusher plant	Building, rubble, crushed stone
Geo. W. Hutchinson.	Bettendorf	Wapsipinicon		Hand work	Building, rubble, macadam
LeClaire Stone Co.	Bettendorf	Wapsipinicon	Compact, white lime stone and dolomite	Steam drills, derricks and crusher plants	Dimension stone, rubble, crushed stone
	LeClaire	Anamosa			
Henry G. Schmidt	Davenport	Wapsipinicon	Coarse dolomite	Hand work	Building, rubble, macadam
F. G. Engelhart	Dixon	Anamosa	Coarse dolomite	Hand work	Building, rubble, macadam
H. Witt	Gambril	Anamosa	Coarse dolomite	Hand work	Building, rubble
Morgan Orndorff	Longgrove	Anamosa	Coarse dolomite	Hand work	
Rock Island Crushed Stone Company	Buffalo	Wapsipinicon	Compact, argillaceous limestone	Steam crusher plant, and hoist and air drills	Crushed stone

TAMA COUNTY.

Lester L. Houghton	Garwin	Kinderhook	Oölitic limestone	Hand work	Building, rubble
C. J. Stevens	Montour	Kinderhook	Oölitic limestone	Hand work	
W. F. Ward	Montour	Kinderhook	Oölitic limestone	Hand work	

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
			VAN BUREN COUNTY.		
R. N. Greene........	Douds Leando....	St. Louis	White, hard limestone	Hand work...........	Building, rubble
Grant Hanshaw......	Douds Leando....	St. Louis	White, hard limestone	Hand work...........	Building, rubble
W. F. Salter.........	Douds Leando....	St. Louis	White, hard limestone	Hand work	
Louis Sperbeck......	Douds Leando....	St. Louis	White, hard limestone	Hand work	
S. D. Fellows........	Keosauqua.......	St. Louis	White, hard limestone	Hand work...........	Building, rubble
W. W. Price.........	Keosauqua.......	St. Louis	White, hard limestone	Hand work...........	Building, rubble
Oscar Dulin.........	Selma............	St. Louis	White, hard limestone	Hand work	
Levi Parkins.........	Selma............	St. Louis	White, hard limestone	Hand work	
Wm. Michael........	Selma............	St. Louis	White, hard limestone	Hand work...........	Building, rubble
			WAPELLO COUNTY.		
F. A. Venator.......	Chillicothe........	St. Louis	Hard, compact white limestone...	Hand work	
Andrew Lames	Dudley...........	St. Louis	Hard, compact white limestone...	Crusher plant	Crushed stone, rubble, riprap
T. L. Stevens........	Dudley...........	St. Louis.........	Hard, compact white limestone...	Hand work...........	Building, rubble, riprap

W. J. Free	Eddyville	St. Louis	Hard, compact white limestone	Hand work	
J. A. Lafferty	Eddyville	St. Louis	Hard, compact white limestone	Hand work	Building, rubble
C. B. Castle	Ottumwa	St. Louis	Hard, compact white limestone	Hand work	
Charles Chilton	Ottumwa	St. Louis	Hard, compact white limestone	Crusher plant	Building, rubble, crushed stone

WASHINGTON COUNTY.

Jas. McCreedy	Ainsworth	Osage	Hard, heavily bedded, gray limestone	Hand work	
Moses Farber	Brighton	St. Louis	Fine grained, compact limestone	Hand work	Rubble
Lee Morris	Brighton	St. Louis	Fine-grained, compact limestone	Hand work	Dimension, flagging, rubble, riprap
W. T. Eckels	Washington	Osage	Hard, heavily bedded, gray limestone	Hand work	Building, rubble
William Hayes	Washington	Osage	Hard, heavily bedded, gray limestone	Hand work	Building, rubble
J. H. Humston	Washington	Osage	Hard, heavily bedded, gray limestone	Hand work	Building, rubble
R. C. Varney	Washington	Osage	Hard, heavily bedded, gray limestone	Hand work	Rubble
H. Batterson & Cornwell	Westchester	Osage	Hard, heavily bedded, gray limestone	Hand work	
A. E. Knotts	Westchester	Osage	Hard, heavily bedded, gray limestone	Hand work	Building, rubble, crushed stone
C. C. Owen	Westchester	Osage	Hard, heavily bedded, gray limestone	Hand work	

DIRECTORY OF IOWA LIMESTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
			WEBSTER COUNTY.		
M. B. McBane	Fort Dodge	St. Louis	White limestone and magnesian limestone	Hand work	
John Quinn	Tara	St. Louis	White limestone and magnesian limestone	Hand work	
			WINNESHIEK COUNTY.		
A. W. Kramer	Castalia	Maquoketa	Soft, yellow dolomite	Hand work	Building, rubble

DIRECTORY OF IOWA SANDSTONE QUARRIES BY COUNTIES.

CLAYTON COUNTY.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
Clayton White Sand Company..........	Clayton	Saint Peter..........	White sand.........	Hand work and sluice-way.........	White sand
E. W. & H. D. Kregel	Garnavillo				
C. G. Stickfort	Garnavillo				
Wm. Jones..........	McGregor				

CLINTON COUNTY.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
John Sherman.......	Calamus				

DECATUR COUNTY.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
William Fox.........	Davis City........	Missouri............	....	Hand work	

DES MOINES COUNTY.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
Geo. Gibson.........	Danville..........	Des Moines.........	White to yellow.....	Hand work	
J. W. Pritchard......	Danville..........	Des Moines.........	White to yellow.....	Hand work	
Frank Benner........	Danville..........	Des Moines.........	White to yellow.....	Hand work	
R. O. Wilson........	Danville..........	Des Moines.........	White to yellow.....	Hand work	

DIRECTORY OF IOWA SANDSTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipment	Products
HARDIN COUNTY.					
Enoch Ansell	Eldora	Des Moines	Red sandstone	Hand work	
Fred Berninghausen	Eldora	Des Moines	Ferruginous	Hand work	Rubble and dimension
Lee B. Marks	Eldora	Des Moines	Ferruginous	Hand work	Rubble
Harry Grieves	Steamboat Rock	Des Moines	Ferruginous	Hand work	Rubble
JASPER COUNTY.					
John Dooley	Newton	Des Moines	Ferruginous	Hand work	Rubble
E. E. Lanphier	Newton	Des Moines	Ferruginous	Hand work	Rubble
Daniel A. Munger	Newton	Des Moines	Ferruginous	Hand work	Rubble
JONES COUNTY.					
Roy Rummel	Olin				
KEOKUK COUNTY.					
Jno. Crocker	Delta	Des Moines	Friable	Hand work	Rubble

LEE COUNTY.

Chas. W. Deeds	Denmark	Osage	Gray to yellow, magnesian	Hand work	Rubble
Peter Kelly	Keokuk	Osage	Gray to yellow-brown	Hand work	Rubble
J. P. Kennedy	Montrose	Osage	Gray to yellow-brown	Hand work	Rubble
Geo. E. Craig	West Point	Osage	Gray to yellow-brown	Hand work	Rubble
H. J. Neuweg	West Point	Osage	Gray to yellow-brown	Hand work	Rubble

MARSHALL COUNTY.

A. E. Judge	Marshalltown	Des Moines	Ferruginous	Hand work	Rubble

SCOTT COUNTY.

John Kress	Buffalo	Des Moines	Gray-white, friable	Hand work	Rubble

TAMA COUNTY.

Albert E. Coleman	Butlerville	Kinderkook	Gray-blue, argillaceous	Hand work	Rubble
Squire Hall	Butlerville	Kinderhook	Gray-blue, argillaceous	Hand work	Rubble
Fetter Hall	Garwin	Kinderhook	Gray-blue, argillaceous	Hand work	Rubble

VAN BUREN COUNTY.

Ira White & Son	Keosauqua	Osage	Gray	Hand work	Rubble and ashlar

DIRECTORY OF IOWA SANDSTONE QUARRIES BY COUNTIES—CONTINUED.

Firm Name	Location of Quarry	Geological Horizon	Kind of Stone	Quarry Equipmen	Products
			WEBSTER COUNTY.		
Albee Sandstone Co.	Ft. Dodge	Des Moines	Gray to red, variable	Hand work	Rubble and building
Geo. M. Kepner	Ft. Dodge	Des Moines	Gray to red, variable	Hand work	Rubble and building
A. E. Harvey	Ft. Dodge	Des Moines	Gray to red; variable	Hand work	Rubble and building
Ft. Dodge Sandstone Co.	Lehigh	Des Moines	Gray to red, variable	Hand work	Rubble and building
J. P. Feller	Tara	Des Moines	Gray to red, variable	Hand work	Rubble and building
John F. Gustafson	Evanston	Des Moines	Gray to red, variable	Hand work	Rubble and building

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